JULY 1957

THE WELDING JOURNAL

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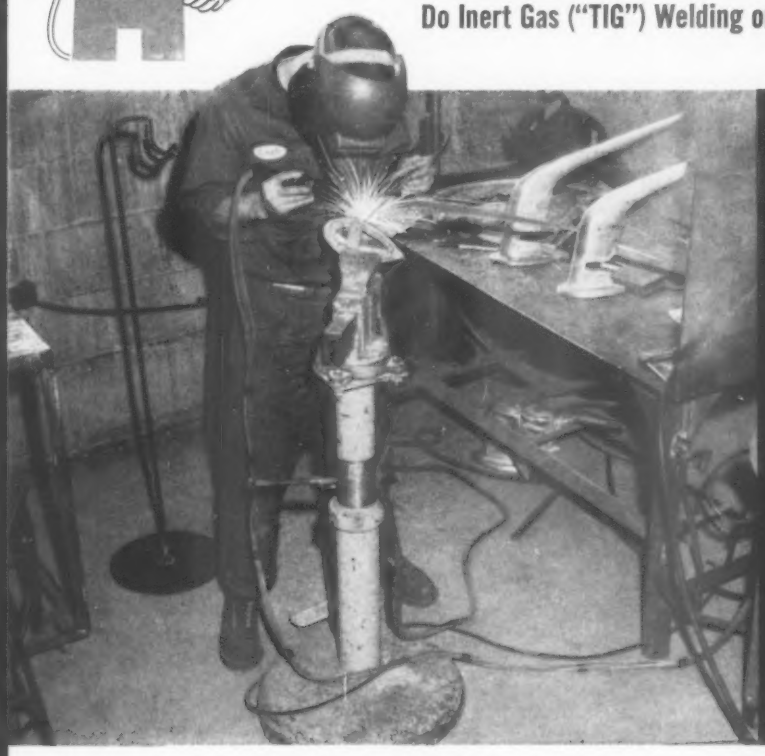

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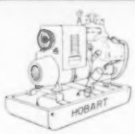

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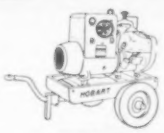

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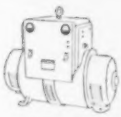

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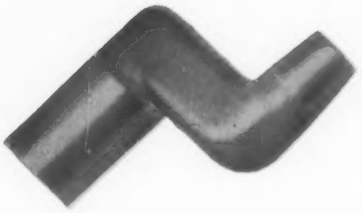

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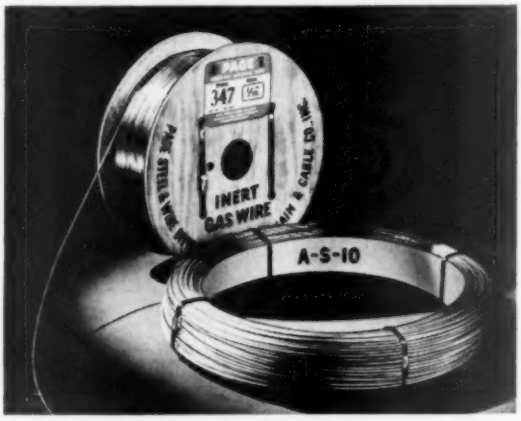

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YIELD POINT AND BRIDGE STRESSES

Is too much importance being attached to "yield point" in determining the allowable steel stresses in dynamically-loaded structures?

Reviewing available information on fatigue in a study of welded bridges, three things stand out—fatigue strength does not significantly increase with an increase in yield point; difference in the fatigue strength of riveted or welded connections is insignificant; the relative freedom from actual fatigue failures in railroad bridges.

Pennsylvania Railroad Standard Bridge Specifications from 1897 to 1928 required the use of "soft steel" with a yield point of 28,000 psi. However, compare the following requirements for ductility in these old specifications with the present ASTM A7 specifications, "Elongation 25%, Reduction 50%". "A piece of each sample bar shall be bent cold and closed up against itself . . . . without developing any crack or flaw . . . ." "The ductility . . . . must be such that a punched hole $^{7}/_{8}$ in. diameter, the center not more than $1^{1}/_{2}$ in. from edge, may be enlarged by drifting to a diameter 50% greater than the original hole without cracking the specimen at any point."

Many bridges still in service on heavily-traveled sections of the Railroad were built over 50 years ago under these specifications with allowable stress in tension of 16,000 psi, and designed for a live load equal to Coopers E-50 as against present-day E-72 live load requirements. Fatigue failures have been confined to overstressed minor details. Welding repairs made over the past twenty-five years have had no effect on fatigue failures.

Possibly, bridge engineers should be more concerned with failure from brittle fracture of steel with low notch toughness than fatigue failure. The spectacular bridge failures, excepting those caused by severe overloads, have been by brittle failure.

It is quite possible that the actual factor of safety in case of a dynamically-loaded structure is greater with a low-yield-point ductile steel than a high-yield-point steel with lower ductility even though the unit stress was the same in both cases.

There is need for further research along these lines.

John E. South

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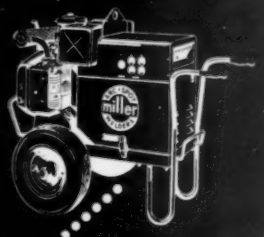

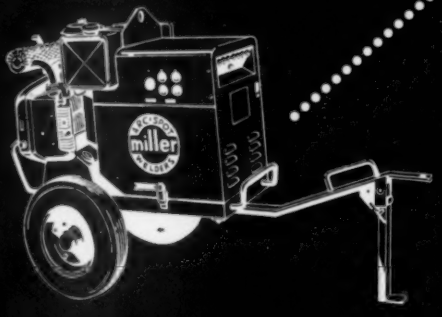

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1957 ADAMS LECTURE

EVOLUTION OF HIGH-TENSILE WELD METAL WITH LOW-HYDROGEN ELECTRODES

BY D. C. SMITH

High-tensile weld metal developments have kept pace with high-tensile steels since the advent of low-hydrogen iron-powder electrodes

DeWITT C. SMITH is a native of Pleasant Grove, Utah. Received his formal education at the Brigham Young University and Utah State Agricultural College where he received a B.S. and M.S. in chemistry. His studies for a Ph.D. were done at the George Washington and Maryland Universities, finishing at Maryland with a major in Physical Chemistry.

In 1934 he went to work for the National Canners Association as assistant chemist and in 1935 transferred to the National Bureau of Standards as testing engineer. In 1937 he was employed by the Harnischfeger Corp., Houses Division, as a research engineer and in 1942 transferred to the Electrode Division of Harnischfeger Corp. as Chief Metallurgist, engaged in research and development of arc-welding electrodes and production quality control.

He has served on various Ordnance Advisory Committees and on AMERICAN WELDING SOCIETY Committees; as Chairman of ASM Committee on selection of welding electrodes for Metals Handbook 1955 supplement. At the present time, he is serving as chairman of AWS-ASTM Filler Metals Committee.

At the same time, he has conducted various research projects on welding and has written several articles and papers on welding electrodes and their applications, some of which have been published in THE WELDING JOURNAL.

ABSTRACT. The evolution of high-tensile weld metal (100,000 to 300,000 psi) commenced with the introduction of low-hydrogen electrodes during World War II. Covered electrodes containing cellulosic combustible materials and/or hydrogen-bearing mineral-type coatings producing an acid slag, as compared to the low-hydrogen basic type, were never satisfactory for producing weld deposits much above 100,000 psi, particularly when the work had to be welded with little or no preheat. Some of the causes underlying the unsatisfactory performance of the conventional type coatings and how the evolution of higher-strength weld metals has kept pace with the steels are given.

Variable moisture contents of the coating caused erratic and unpredictable results with the first lime-ferritic commercial electrode (NRC-2A) developed for the welding of steels of high hardenability. The important role of moisture (or hydrogen) in causing weldment failures was not too well recognized until after World War II.

A Navy-NEMA committee developed a weld metal of approximately 110,000 psi minimum yield and 20% elongation with high notch toughness when applied under highly restrained conditions with little or no preheat. In studying this and electrodes with similar coatings (low hydrogen), the Navy Department, Bureau of Ships, noted the detrimental effect of moisture in the coatings and established maximum limits for moisture in the coatings of electrodes purchased for military purposes.

Results of an investigation by our laboratory, sponsored by the Ordnance Corps, U. S. Army, are given on (1) the effect of moisture in the coatings of MIL-E-986B, Types MIL-230-16 and MIL-260-15, electrodes on the welding of armor plate, (2) the conditions required to restore electrodes to their original usability after they have absorbed a harmful amount of moisture and (3) the rates at which moisture is absorbed by the coatings at various humidities and temperatures.

It was later discovered that the nickel-molybdenum-vanadium type of weld metal was unsatisfactory for the usual heat treatments, such as 1150° F stress relieved or quenched and tempered in the 900–1200° F temperature range.

Three different high-strength-alloy weld-metal compositions were developed to overcome the temper brittleness of the nickel-molybdenum-vanadium type for use in cast armor repair service and their properties are given.

Four types of heat-treatable high-strength weld-metal compositions developed and used for aircraft application in the tensile-strength range of 125,000–210,000 psi are described and their properties are given.

The development of ultra-high-strength steels (220,000–300,000 psi) is reviewed and weld metals developed for use in their fabrication. Six different types of ultra-high-strength weld metal are proposed and the following properties investigated: Transverse and all-weld metal tensile and yield strengths, ductility, hardness, transverse and longitudinal bending properties, toughness as measured by the Charpy V-notch impact, Jominy hardness, grain size determination and Lehigh restraint cracking tests. Most of the tests were made on the weld metal tempered over a wide range of temperature.

The results of the ultra-high-strength weld metal development indicate that it is difficult to select any one of these types as the best. Types C and D showed best ultra-high-strength properties at a 400–500° F tempering range. Types A and B appeared best in the 500–700° F range. Type E seemed more suitable in 600–800° F tempering range and Type F in the 1050–1200° F range. An understanding of the properties desired is necessary to make an intelligent selection from among these six types. Each has an application suitable for the particular service required.

Results from this research show that practically all the ultra-high-strength steel compositions can be matched with weld metal. Furthermore, it is believed that enough data have been obtained to show that it is possible to use these electrodes under service conditions to fabricate ultra-high-strength steels.

Introduction

Mr. Chairman, Members and Guests of the AMERICAN WELDING SOCIETY, we have convened this morning for the fifteenth annual lecture honoring Dr. Comfort Avery Adams. Unlike many of my predecessors, I have not had the good fortune of knowing personally Dr. Adams but I have, with many others, greatly benefited from the pioneering achievements, guidance and teachings in research of this great counselor and founder of the AMERICAN WELDING SOCIETY.

In these days when we are so conscious of our heritage of freedom, we in the welding industry recognize how rich is our heritage from such an indomitable pioneer of welding as Dr. Adams. The status of welding today serves as a monument to his farsightedness and the wisdom of his guiding hand in its beginning. I sincerely hope that the subject of this lecture is one that he himself might have selected.

Growing Importance of High-Strength Steels

I selected the subject of "The Evolution of High-Tensile Weld Metal with Low-Hydrogen Electrodes" because I have seen the rise in use of higher and higher tensile steels and we in the welding industry are now actively engaged in developing and producing welding electrodes that will weld these new extra-high-strength steels.

A few years ago, one of the major aircraft companies showed that existing alloy steels such as 4340 possessed dormant properties that could be utilized for aircraft construction at tensile strengths up to approximately 280,000 psi by simply lowering the draw temperature below the usual 800° F. Prior to this, 200,000 psi was considered about the maximum tensile strength that was safe and still retain sufficient ductility and toughness. Since this time, several of the major aircraft factories have developed structures designed around these ultra-high-tensile steels.

That this trend to development and use of ultra-high-strength steels is in the foreground of thinking of our leading research directors and metallurgists is illustrated by statements such as that of A. B. Kinzel, vice-president of research for Union Carbide and Carbon Corp., who in his 1956 Burgess Memorial Lecture before the Washington Chapter of the Society for Metals stated that metallurgy is on the threshold of its greatest advances. Better pig iron will be made so that electric furnace steel will be cheaper than open-hearth steel. The cost differential between alloy steels and carbon steels will be less and consequently the total production of alloy steel will increase. Also,

future research will discover more about vacuum melting and we will then have new, higher-quality alloy steel, and metallurgists will produce commonly used steels with tensile strengths exceeding 280,000 psi and possessing excellent ductility. Also, Van H. Leichliter, vice-president of American Steel and Wire Division, in his McFarland Award Lecture at Penn State University stated that today wire for suspension bridges has tensile strength up to 250,000 psi. Recently high carbon wire has been drawn with a tensile strength of 500,000 psi and pure iron crystals of 1,900,000 psi have been created in a laboratory. In referring to the importance of the metallurgist in the Electomic Age, Mr. Leichliter said "that history made it clear in our complex world of knowledge and invention and development that each of us has a value in direct proportion to our ability to appreciate and work with the over-all team." In this team concept he visualized the metallurgist as the quarterback by reason of the fact that he stands astride the raw material of the metals of the earth.

Like the opinions of these and other authorities in this field, I feel that we are now on the threshold of an era when industry will be welding these ultra-high-strength steels as common practice and electrodes will be available for this purpose.

High-Tensile Weld Metal

Weld metal with tensile strengths exceeding 70,000 psi has been generally regarded by the industry as high tensile providing it contains deliberate additions of elements such as manganese, molybdenum, silicon, chromium, nickel, or vanadium to increase the tensile strength above the 60,000 psi. If, however, the increased tensile strength is produced from manganese (not exceeding 1.00%), silicon (not exceeding 0.80%), or possible small amounts of titanium, electrodes have been classified by AWS as mild steel and not in the high-tensile alloy class. Staying under these limits for manganese and silicon and keeping the other alloys below concentrations that are considered residuals, the tensile strength can seldom go beyond 85,000 psi.

For the purpose of this lecture, however, weld metal of 100,000 psi and up will be regarded as high tensile and the development of weld metal designed for making weldments in the range of 100,000 to 300,000 psi will be considered. Alloy additions to the weld metal are necessary to reach this tensile strength range so they could likewise be classified as alloy high-tensile weld metals. The details of this work in the development research have been omitted in order to emphasize the over-all results and conclusions.

Limitations of the Conventional Type Coatings

In this country, arc welding of plain-carbon structural steels was developed as a process of general importance during World War I using bare electrodes primarily. Bare electrode welding, while satisfactory for many purposes, results in weld deposits of very low ductility and low shock loading resistance. Development of electrode coatings with organic or gas-forming materials producing a reducing atmosphere around the arc, as well as slag-forming oxides, enabled a deposition of weld metal higher in ductility, shock loading resistance and tensile strength. Furthermore, the speeds of welding in all positions were greatly increased with these covered electrodes. Arc-welding applications were soon increased to include low-alloy steel structures where the steels were used in the as-rolled or normalized condition.

Covered electrodes containing cellulosic materials, alloyed sufficiently to raise the weld metal strength comparable to that of high-strength base metal, were developed and used with a minor degree of success when sufficient preheat and postheat treatments were used. Preheating and or heat treatment after welding was often impossible and or impractical. Even with the use of preheat and postheat treatment, electrode weld metal with tensile strengths above 110,000 psi were seldom used or considered suitable with these conventional type coated electrodes.

It was not until this country's entry into World War II that the American industry was called upon to apply the arc-welding process to fabrication of alloy-steel structures which had considerably higher tensile strength and resistance to impact loading. Steels commercially heat treated in heavy and sometimes complex sections were used for structures in combat vehicles.

Arc-welding applications involving high-tensile steel are limited by the formation of a hard brittle martensitic zone adjacent to the weld wherein cracks may occur. This cracking may be the result of additional stresses caused by hydrogen. The most commonly accepted theories for the behavior of hydrogen are given by Stout and Doty,[1] in brief as follows:

"Welds made with hydrogen-producing electrodes absorb hydrogen in the molten metal pool. Some escapes when it solidifies and some is retained and diffuses from the molten weld metal to adjacent base metal which has been austenitized by the heat of welding and which in this state has a high capacity for hydrogen absorption. As the weld metal cools, its capacity for holding hydrogen in solution diminishes. Thus the base metal immediately adjacent to the weld becomes highly charged. The austenite, if rapidly cooled, which results from welding heavy structures, may retain large amounts of hydrogen. The retained austenite may be supersaturated with hydrogen and, when the austenite transforms to martensite, cracking may occur in the newly formed microstructure. The cracking is brought about through (*a*) the embrittling effects of hydrogen in the martensite lattice, (*b*) the dynamic stresses of the austenite-martensite transformation superimposed on shrinkage stresses and (*c*) the high aerostatic pressure of molecular hydrogen in microholes."

Cottrell,[2] in discussing the effect of hydrogen on the mechanical properties of steel, shows the solubility of hydrogen in iron and steel and gives a theoretical relationship for welds cooling at different rates containing a given volume of hydrogen per given weight of weld metal. These data are shown in Figs. 1 and 2.

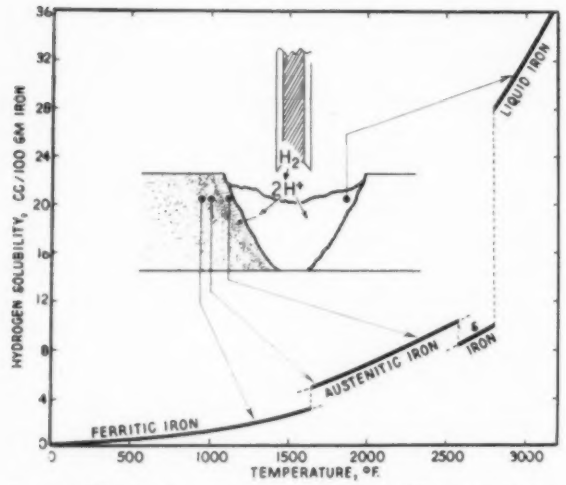

Fig. 1 Effect of temperature on the solubility of hydrogen in iron at atmospheric pressure

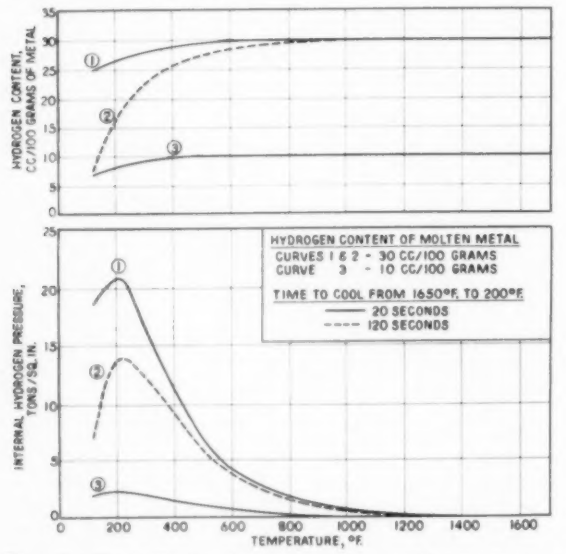
HYDROGEN CONTENT, CC/100 GRAMS OF METAL
INTERNAL HYDROGEN PRESSURE, TONS/SQ. IN.
TEMPERATURE, °F
HYDROGEN CONTENT OF MOLTEN METAL
CURVES 1 & 2 - 30 CC/100 GRAMS
CURVE 3 - 10 CC/100 GRAMS
TIME TO COOL FROM 1650°F TO 200°F
20 SECONDS
120 SECONDS

Fig. 2 Theoretical relationships for welds cooling at different rates and containing different amounts of hydrogen

Whenever the base metal contains sufficient alloy and/or carbon to form a martensitic zone adjacent to the weld, a preheat of 300 to 500° F is recommended to prevent cracking if hydrogen-producing electrodes are used. In the absence of the superimposed stresses due to hydrogen, this hard martensitic zone may be produced without cracks with little or no preheat and on subsequent tempering at a suitable temperature a tough microstructure results.

A welding process which is applicable to heat-treated high-hardenability steels without the use of preheat or postheat treatment was needed. This was accomplished early in World War II through the use of mineral covered austenitic electrodes, Types 310, 307 and 308 Mo. While the hardest martensitic weld zone is developed in the base metal on the first pass, the weld metal deposit has the properties of a reasonably high yield strength and excellent ductility at practically all rates of strain which relieves these stresses sufficiently to prevent cracking. This hard zone formed from the first pass is tempered with subsequent weld-metal passes to further reduce the stresses and eliminate cracking.

Results of work done for the Ordnance Corps, U. S. Army, through a development contract of our company with Watertown Arsenal, showed that 1½-in. armor plate weld under high restraint did not develop underbead cracking with these austenitic electrodes with moisture contents up to approximately 3.00% in the coatings. This same armor plate welded with ferritic electrodes developed underbead cracking with moistures as low as 0.30% in the coatings.

The austenitic weld metal dissolves the hydrogen from the arc atmosphere in the molten state and it remains in solution as the weld metal cools to ambient temperature, whereas the ferritic weld metal rejects the hydrogen and enough of it diffuses into the heat-affected zone to cause cracking. Unfortunately, we have not been able to make hydrogen-free electrodes but through improved formulation and manufacturing conditions, particularly higher finishing temperature, have been able to reduce the moisture content in the coatings of commercial low-hydrogen ferritic electrodes to below 0.20%.

Austenitic-weld-metal deposits of these types are only around ninety-odd-thousand psi in ultimate strength and this, together with their high cost and the scarcity of nickel, made it desirable to develop higher-tensile ferritic electrodes for welding high-tensile steels.

Thus with the stimulus given through the great need of a high-tensile-strength electrode brought on by the war, the low-hydrogen-type coating in its present form was born in America. Similar type electrodes, but with a lower-tensile weld metal, were developed and used commercially long before this time, but the war-time volume fabrication of difficult-to-weld steels made their introduction in this country more favorable than during normal times.

Low-Hydrogen-Type Coatings

The limitations in magnitude of tensile strength of the weld metal found in the use of conventional coatings are explained adequately by Mathias and Bunk.[2] Some of these performance deficiencies are: (1) their inability to allow the introduction of reducing type of alloy additions such as silicon, manganese, chromium, vanadium, etc., without badly upsetting performance characteristics. A heavy loss of these elements results and their state of combination in the weld is always questionable. (2) Their inability to weld drastically air-hardening steels without the formation of underbead cracking unless preheated.

The use of the low-hydrogen coatings on an electrode makes it possible to deposit sound weld metal in a structural joint higher in carbon content at lower preheats than the conventional coatings and it also enables the deposition of a low-carbon alloy weld metal that can be heat treated to a low-carbon tempered martensite. This type of a structure, as opposed to the higher

transformation product (Banite, Sorbite, etc.), gives a very tough and ductile weld metal. Low-carbon alloy steels that can be heat treated above 100,000 psi for commercial use have already made their debut and are gaining in popularity with many fabricators.

Electrodes capable of welding these high-tensile, heat-treated steels that will give comparable tensile strengths and low-temperature impact resistance as deposited and stress relieved were needed and are now available. High-tensile steel casting uses are increasing and the need for electrodes for use in their repair is growing. Thus, the trend to higher-strength rolled and cast steels by the industries increased the need for electrodes of comparable strength for use in their fabrication and repair. We in the industry feel that the design and production of such electrodes have kept pace with the alloy steel developments.

High-Tensile Weld Metal Designed for Use with Little or No Preheat

At the start of World War II, the War Production Board in order to conserve strategic materials requested the National Research Council to initiate a program to develop ferritic electrodes that could replace the austenitic electrodes for the welding of armor. Out of the efforts of this program was developed the electrode called NRC-2A. This was a 1.75% manganese, 0.35% molybdenum alloy low-hydrogen-type electrode with approximately 100,000 psi tensile strength. Many tons of this electrode were used without preheat for fabricating armor weldments $^1/_2$-in. and less (up to $^1/_2$-in. thickness), but heavier armor required preheats of 200° F or more. Without preheat, erratic and unpredictable cracking of weld metal and base metal occurred. Preheating, however, was impractical for many fabricators and very few of these electrodes were used for welding heavy armor. The development of this electrode did not reach completion before hostilities ended, but the work at Battelle Memorial Institute on this NRC-2A electrode indicated that hydrogen in the electrode coating was responsible for all the erratic results.

The effect of moisture in coatings of electrodes was not fully evaluated until the Navy Department, Bureau of Ships, in cooperation with the National Electrical Manufacturers Association formed a committee of technical personnel from both organizations and initiated a program to develop an electrode that would deposit high-yield, notch-tough, ferrous weld metal for welding armor steel without preheat. The first electrode explored by this committee was the NRC-2A. It was soon shown that the erratic and unpredictable properties of the NRC-2A electrode when used without preheat were due to variable moisture contents of the coating. It was also noted that, even with the moisture reduced to a very low value (0.2% or less, determined at 2400° F), a minimum preheat of 200° F was necessary when making multipass welds in heavy armor.

The weld-metal compositions finally developed which met the original objective, namely, 90,000 and 110,000 psi minimum yield strength, 20% minimum elongation, and high notch toughness when used under highly restrained conditions with little or no preheat, were alloys of nickel-molybdenum-vanadium. The details of their development, properties, applications and usability of these electrodes are described by Frank *et al.*[4] These electrodes are now known and classified by AWS-ASTM as E10015-16 and E12015-16 and by the Military Specification MIL-E-986 as Class MIL-230-16 and MIL-260-15. Table 1 gives typical mechanical properties and nominal compositions of these, the first successful ferritic electrodes developed for welding high-tensile steels without preheat.

Table 1—Mechanical Properties, As-Welded, and Nominal Alloy Composition of MIL-230-16 and MIL-260-15 Electrode Weld Metal

	MIL-230-16	*MIL-260-15*
Tensile strength, psi	105,000	123,000
Yield strength, psi	95,000	116,000
Elongation in 2 in., %	25.0	21.0
Reduction in area, %	60.0	55.0
Impact properties, ft-lb (Charpy V):		
70° F	95	68
−40° F	32	24
Chemical analysis, %		
Carbon	0.07	0.07
Manganese	0.75	0.95
Silicon	0.45	0.40
Nickel	1.75	1.80
Molybdenum	0.30	0.75
Vanadium	0.10	0.28
Phosphorus	0.018	0.019
Sulfur	0.019	0.018

Effect of Moisture in the Coatings of 100,000 and 120,000 Psi Low-Hydrogen Electrodes

The Navy Department, Bureau of Ships, noting the detrimental effect of moisture in the coatings of the nickel-molybdenum-vanadium and similar low-hydrogen type electrodes established maximum moisture limits permissible in the coatings of electrodes purchased for military purposes; namely, 0.2% for the 110,000 grade, 0.4% for the 90,000 grade and 0.8% for the 70,000 grade.

Since Navy armor is different from Ordnance armor, our company by a contract with Watertown Arsenal, sponsored by the Ordnance Corps, U. S. Army, investigated (1) the effect of moisture in the coatings of MIL-E-986B, Types MIL-230-16 and MIL-260-15, electrodes on the welding of armor, (2) the conditions required to restore the electrodes to their original usability after they have absorbed a harmful amount of moisture and (3) the rates of moisture absorption by the coatings at various humidities and temperatures.

Briefly, the test joint (Fig. 3) recommended by the Ordnance Research Advisory Committee and used by this investigation consisted of depositing four weld-metal layers, two on each side, in a double-vee joint, 9 in. long in the center of $1^1/_2$- x 16- x 24-in. long armor

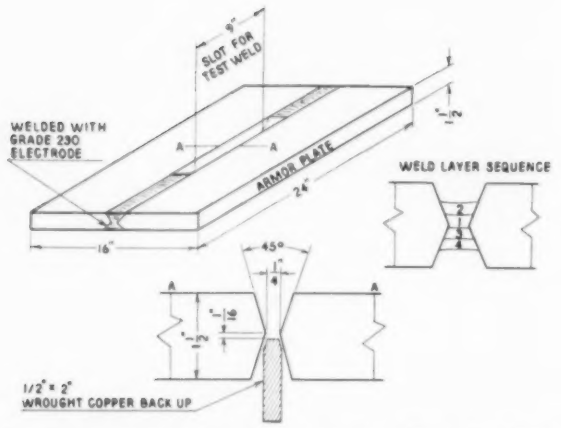

Fig. 3 Test joint used in determining the effect of moisture in Mil-230-16 and Mil-260-15 electrode coatings

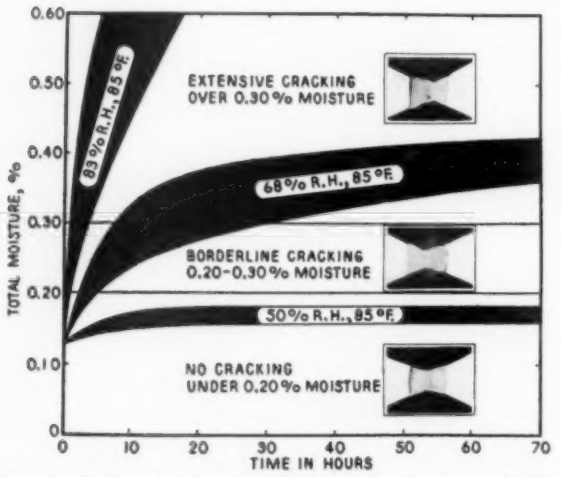

Fig. 4 Rates of moisture absorption by coatings of Mil-230-16 and Mil-260-15 electrodes and extent of weld-metal cracking in armor plate

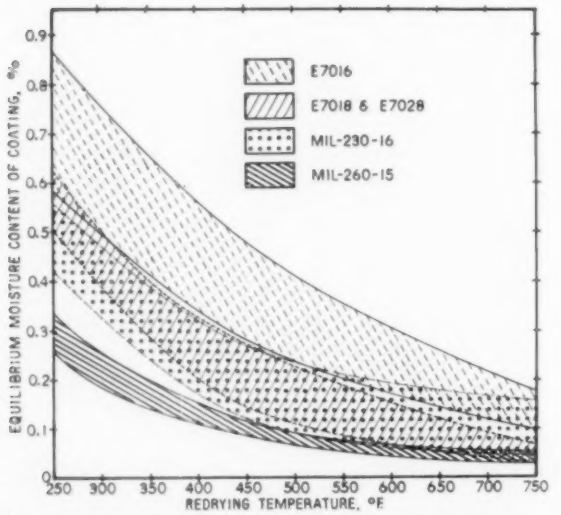

Fig. 5 Redrying characteristics of commercial low-hydrogen medium and high-tensile electrodes

plate, at 150° F preheat and interpass temperature, then air cooled to room temperature and X-rayed at 4, 24, 48 and 72 hr after completion. The weld beads were deposited in straight progression from start to finish. The root bead required two $^{3}/_{16}$- x 14-in. electrodes and the second, third and fourth layers required three each.

The conclusions reached from this investigation are shown in Figs. 4 and 5. Moisture in the coatings of these low-hydrogen high-tensile electrodes is an important factor in causing failures when used in the fabrication of high-tensile steel. In this highly stressed double-vee joint, moisture contents above 0.30% resulted in weldment failures due to cracking, primarily in the fusion zone. When electrodes with moisture contents 0.20% or lower were used, sound weldments were made under similarly stressed conditions. Electrodes having moisture contents in the approximate range of 0.20–0.30% were borderline in making sound weldments under these same conditions.

Other factors, such as preheat, operator technique, surface profile of the weld metal and factors affecting the merging or washing up of the weld metal on the side walls of the scarfed joint, are all important in making sound weldments. It was found early in this investigation that the notch effect at the junction of the weld and base metal was a potential crack starter and often masked the effect of moisture. As the tensile strength of the weld metal increased, these variables became more important and the masking effect became more pronounced. Grinding the weld-metal edges of the top layers to a smooth radius or tilting the test plate at an 8-deg angle downward during welding helped to reduce this notch effect of the unfilled four-layer welded joint used in this investigation.

The adverse effects of hydrogen in high and ultra-high tensile steels used in the aircraft industries have been particularly noted recently on parts that have been electroplated and not given a subsequent dehydrogenation treatment. The introduction of hydrogen into the metal through the electroplating process embrittles the metal and it becomes necessary to dehydrogenate these parts by heating 4 to 5 hr at temperatures of 400 to 500° F. Thus the control of moisture and these other variables were necessary to enable the further development of higher tensile weld metal.

Moisture Absorption Properties of High-Tensile-Electrode Coatings

Since moisture in the coatings of high-tensile electrodes designed for use with little or no preheat is such an important factor in causing weldment failure, a study of the moisture absorption and redrying characteristics of these electrodes was needed to enable their proper application, handling and storage.

Figure 4 shows the rates of moisture absorption of two types (E10016 and E12015) and three brands of high-tensile electrodes determined in our laboratory. The apparatus and method of making this study are described in our paper.[5]

The rates of moisture absorption varied considerably among the six different electrodes at the 85% relative humidity. At 68%, the rates dropped off quite noticeably and, at 50% relative humidity, the rates are less than 0.10% in a 180-hr period for all brands in both types.

Figure 5 shows the redrying characteristics of the six high-tensile electrodes investigated. The results show that 700° F in a well-ventilated oven for approximately two hours is ample to lower the moisture to a safe value (below 0.20%). Prolonged drying periods at this or even lower temperatures (500–600° F) and a higher temperature for shorter periods may cause the coating of some brands to become brittle and crack.

Electrodes stored in open containers at 50% relative humidity require several weeks before harmful amounts of moisture are absorbed. At 40% relative humidity no moisture absorption will take place over an indefinite period. When temperature only is controlled, 175° F is ample to prevent harmful amounts of moisture absorption.

The results of our investigation, then, show that electrodes can be reclaimed after they have absorbed a harmful amount of moisture, providing the coating is not damaged by using temperatures above the recommended values or at extended drying periods at the recommended temperature.

Development of Heat-Treatable High-Tensile Electrodes

There are two general methods of increasing the tensile strength of steel or weld metal. One is by increasing the carbon and/or alloy content without changing the thermal or heat-treating conditions, and the other is through heat treatment without effecting a composition change. This latter method is limited to those compositions high enough in carbon and alloys that will respond to a heat treatment.

The heat-treating properties of steel are important characteristics that make it such a vital material of construction but, as vital as these properties have been in its past uses, recent developments and research have shown that until only recently there have been unused reserved strength in many of the higher-alloy steels. Thus, by just dropping the tempering temperatures of many of these steels, the tensile strength has been increased without the expected drop in ductility and toughness that was formerly associated with higher-strength steels. The composition of the steel or weld metal plays a vital part in obtaining this desired high strength with good ductility and toughness, but the fact remains that several existing commercial steels and castings were discovered that unknowingly contained a suitable composition. Thus, through the process of thermal treatment of steel suitably alloyed, the field has opened up to produce greater possibilities of getting the desired properties of high strength combined with good ductility and toughness through wide temperature ranges.

High-Tensile Electrodes for Cast Armor Repair

The nickel-molybdenum-vanadium alloy combination used to obtain the desired properties of the E12015 (MIL-260-15) without preheat proved to be unsatisfactory for some types of heat treatment. When tempered or stress relieved in the temperature range from 800 to 1200° F, the weld metal becomes brittle and loses its toughness at low temperature.[6] This temper-brittleness phenomenon is generally attributed to precipitation of some kind. In this composition, a vanadium carbide precipitation is possibly the most important factor in producing the brittleness.

Where vanadium concentration is kept under approximately 0.10% and molybdenum under approximately 0.35%, very little, if any, temper brittleness results. Vanadium functions as a good weld-metal grain refiner and is desirable in the weld metal for use in the as-welded condition. In compositions containing higher carbon it does not seem to have as detrimental effects in causing brittleness when stress relieved or drawn in this temperature range as it does when the carbon is low (0.10% and under).

The heat-treating properties of several weld-metal compositions deposited with low-hydrogen electrodes are described in our paper,[6] and is recommended to the reader desiring more detailed information of this subject. It suffices to say that with the development of the nickel-molybdenum-vanadium type by the Navy-NEMA committee parallel development of low-hydrogen weld metal for heat treatment took place.

Again, the wartime volume fabrication created by the Korean emergency stimulated this phase of electrode development. There was a great need of heat-treatable high-tensile electrodes for making repairs of cast armor used in the combat equipment and only the low-hydrogen covered electrodes were suitable.

Castings are grouped into three classifications: A, B and C. Class A castings require a full heat treatment (water quenched from above Ac_1 and tempered to the specified hardness) after repair; Class B requires stress relieving between 1050–1250° F only; and Class C requires no heat treatment after welding. Since types MIL-10016 and MIL-12015 were designed for use with little or no preheat and or postheat treatment, they were satisfactory for repairing the Class C castings only. The NRC-2A, manganese-molybdenum of approximately 100,000 psi in the as-welded condition, was satisfactory for Class A and B castings of the lower tensile strength. Two other types of electrodes were developed and used quite extensively for Class A and B castings repair; namely a $2^1/_2$% chromium —$^1/_2$% molybdenum, and a manganese-chromium-nickel-molybdenum type. The weld-metal mechanical properties of these three types of electrodes, as-welded and stress relieved at 1150° F, are given in Table 2 and Fig. 6, which shows the effects of tempering on the tensile strength after water quenching from above Ac_1. The tensile strength as shown in Fig. 6 covers a range between 100,000–180,000 psi when quenched and tempered, which is sufficient to match those of the castings used for armor purposes. These compositions are by no means all that have been or are being used, but

Table 2—Typical Mechanical Properties, As-Welded and Stress Relieved, of Three Classes of Low-Hydrogen Electrodes Used in the Repair of Cast Armor

	Class 1	*Class 2*	*Class 3*
As Welded			
Tensile strength, psi	100,500	135,000	125,000
Yield strength, psi	88,000	120,000	100,000
Elongation in 2 in., %	20.0	18.0	20.0
Reduction in area, %	46.0	52.0	60.0
Impact, ft-lb, Charpy V			
Room temperature	50	27	59
−40° F	18	9	24
1150° F stress relieved			
Tensile strength, psi	95,000	111,800	112,200
Yield strength, psi	78,000	99,800	100,000
Elongation in 2 in., %	28.0	20.0	22.0
Reduction in area, %	69.0	62.0	65.0
Impact, ft-lb, Charpy V			
Room temperature	78	32	95
−40° F	26	9	31
Weld-metal analysis, %			
Carbon	0.11	0.12	0.16
Manganese	1.85	0.71	1.20
Silicon	0.44	0.40	0.37
Chromium	...	2.72	0.59
Nickel	...	...	1.21
Molybdenum	0.30	0.63	0.29

they do account for the bulk of those used for this type of repair up to the present time.

The author feels, however, that as further investigation is made and experience is obtained, one suitable weld-metal composition such as given in Class 3 weld metal will be developed that can be used for repairing all alloy-steel castings designed for heat treating in the range 125,000–180,000 psi regardless of the cast-steel composition.

High-Tensile Electrodes Designed for Aircraft Fabrication

The aircraft industries have made great progress in the last few years in increasing the strength-weight ratio of structural steels through modified heat-treating processes. Formerly, the philosophy existed in the aircraft industry that high strength and hardness are always associated with dangerous brittleness. For this reason the tempering temperatures were limited to 800° F and above which gave tensile strengths in the maximum range of 180,000–200,000 psi.

MIL-E-8697A (ASG) specification was prepared by the joint efforts of the aircraft industry, Bureau of Aeronautics, and electrode producers to cover the requirements of electrode weld metals designed for heat treatment in the 125,000–200,000 psi range.

Mechanical properties and weld-metal compositions of four typical commercial electrodes designed and used primarily for this service are given in Table 3 and Figs. 7 and 8. Weld metals Nos. 1 and 2 are the same as Classes 2 and 3 used for cast armor repair. Numbers 3 and 4 were designed specifically for the aircraft industry.

Impact strength (Charpy V-notch) quenched and

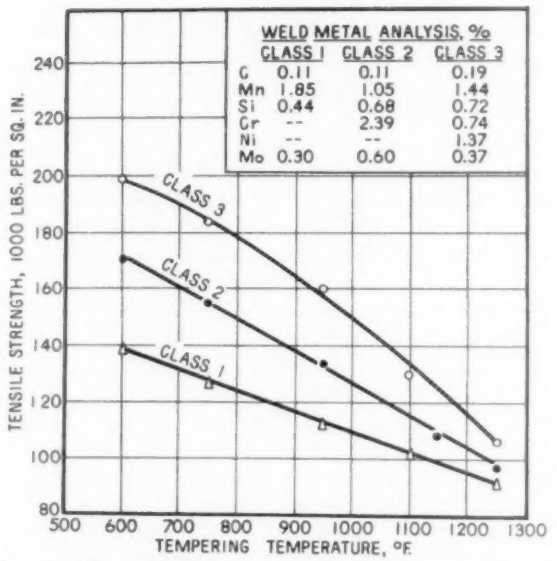

Fig. 6 Effect of tempering on the tensile strength of weld metal of three classes of electrodes used for cast armor repair

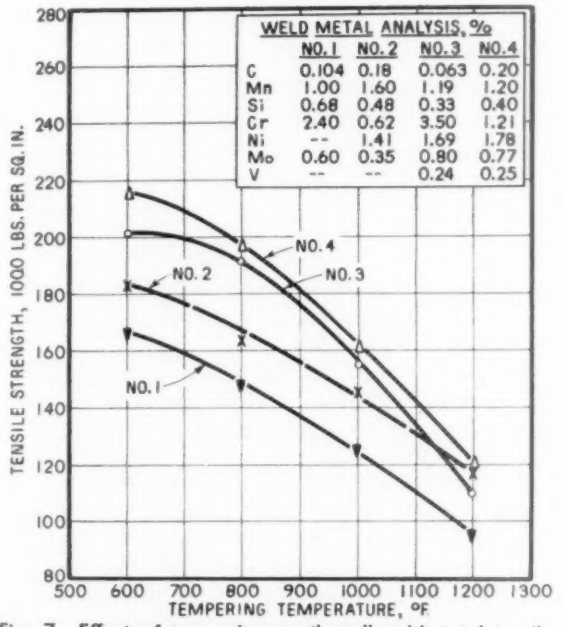
WELD METAL ANALYSIS, %
NO. 1 NO. 2 NO. 3 NO. 4
C 0.104 0.18 0.063 0.20
Mn 1.00 1.60 1.19 1.20
Si 0.68 0.48 0.33 0.40
Cr 2.40 0.62 3.50 1.21
Ni -- 1.41 1.69 1.78
Mo 0.60 0.35 0.80 0.77
V -- -- 0.24 0.25
NO. 4
NO. 3
NO. 2
NO. 1
TENSILE STRENGTH, 1000 LBS. PER SQ. IN.
TEMPERING TEMPERATURE, °F

Fig. 7 Effect of tempering on the all-weld-metal tensile strength of four commercial heat-treatable high-tensile electrodes used in aircraft construction

tempered at 950 and 850° F for weld metals Nos. 2 and 3, respectively, are given in Figs. 9 and 10.

The difference in tensile strengths of these four weld-metal compositions varied from a low of 147,000 psi to a high of 195,000 psi quenched in oil from 1575° F and tempered at 800° F. In the transverse tensile test bar using SAE 4340 base metal these strengths ranged from 172,000 to 200,000 psi. This difference in tensile strength between the all-weld and transverse

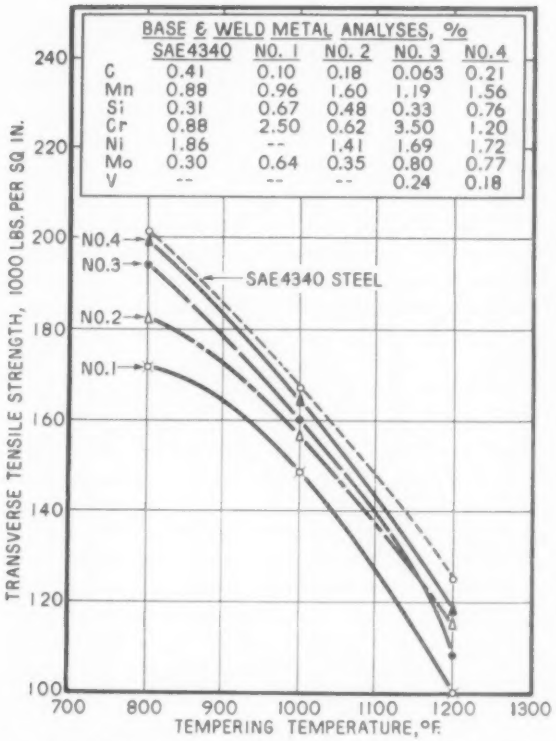

Fig. 8 Effect of tempering on the transverse tensile strength of weldments made with four typical commercial electrodes and SAE 4340 base metal

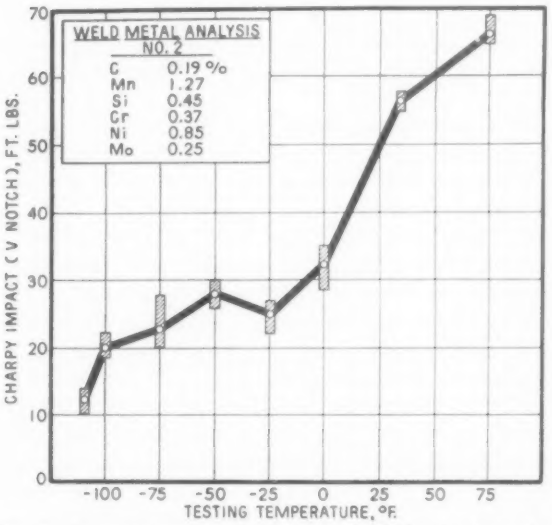

Fig. 9 Impact strength of weld metal of No. 2 electrode. Oil quenched from 1550° F and tempered at 950° F for 12 hr. Tensile strength—130,000 psi

test bars is due to the dilution effect of the base metal, i.e., the weld metal picks up carbon from the base metal to increase its tensile strength. Since much of the structural materials going into aircraft is light gage steel, the dilution effect has been used to a great extent and electrodes of a much lower tensile than the base metal have been used with good results.

Table 3—Mechanical Properties and Weld-Metal Analysis of Four Typical Commercial Electrodes Used for the Aircraft Industry MIL-E-8697A(ASG)

	—Heat treatment—			—Mechanical properties—					—Weld metal analysis, %—				
Electrode	No.	Quenching temperature, °F	Tempering temperature, °F	Base metal	Tensile strength, psi	Elongation in: 1 in., %	2 in., %	Reduction area, %	Location of fracture	C	Mn	Si	Cr	Ni	Mo	V
HT125	1	1575	800	...	147,500*	...	14.3	58.0	...	0.11	1.05	0.68	2.40	...	0.60	...
		1575	1150	...	107,500*	...	18.5	68.0	...	...	...	...	...	...	...	...
		1575	800	4340	172,000†	15.0	7.5	...	W.M.‡	0.10	0.96	0.67	2.50	...	0.64	...
		1575	1150	4340	110,000†	27.0	14.0	...	W.M.	...	...	...	...	...	...	...
HT150	2	1550	800	...	156,500*	...	14.5	58.0	...	0.15	1.34	0.36	0.55	1.29	0.55	...
		1550	1150	...	115,000*	...	18.6	68.0	...	...	...	...	...	...	...	...
		1550	800	4340	182,000†	10.0	5.0	...	W.M.	0.18	1.60	0.48	0.62	1.41	0.35	...
		1550	1150	4340	122,000†	7.5	15.0	...	B.M.	...	...	...	...	...	...	...
		1550	800	4130	180,000†	11.0	...	...	W.M.	...	...	...	...	...	...	...
		1550	1150	4130	120,000†	8.0	16.0	...	B.M.	...	...	...	...	...	...	...
HT180	3	1550	800	...	182,500*	...	11.4	51.0	...	0.18	1.16	0.53	1.13	1.60	0.73	0.24
		1550	1150	...	149,000*	...	16.4	68.0	...	...	...	...	...	...	...	...
		1550	800	4340	195,000†	15.0	8.0	...	W.M.	0.20	1.20	0.40	1.21	1.78	0.77	0.25
		1550	1150	4340	130,000†	2.0	12.0	...	B.M.	...	...	...	...	...	...	...
		1550	800	4140	199,000†	10.0	5.0	...	W.M.	...	...	...	...	...	...	...
		1550	1150	4140	148,000†	...	10.0	...	B.M.	...	...	...	...	...	...	...
HT200	4	1550	800	...	195,000*	...	11.4	51.0	...	0.23	1.61	0.77	1.15	1.63	0.72	0.17
		1550	1150	...	156,000*	...	14.3	54.0	...	...	...	...	...	...	...	...
		1550	800	4340	200,000†	3.0	8.0	...	B.M.	0.21	1.56	0.76	1.20	1.72	0.77	0.18
		1550	1150	4340	135,000†	3.0	13.0	...	B.M.	...	...	...	...	...	...	...

* All-weld metal. † Transverse. ‡ W.M., weld metal; B.M., base metal.

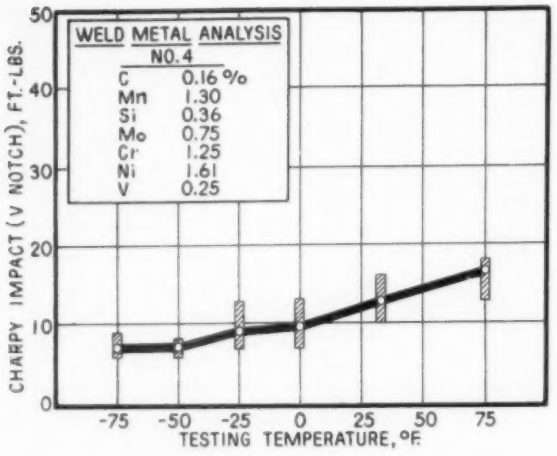

Fig. 10 Impact strength of weld metal of No. 4 electrode. Oil quenched from 1550° F and tempered at 850° F for 12 hr. Tensile strength—175,000 psi

Another type of heat-treatable weld metal used quite extensively for aircraft fabrication is the standard Type 502 (4–6% chromium–0.5% molybdenum) with 0.10% maximum carbon. The excellent heat-treating properties of the weld metal and the ease of application, together with its ready availability, are some of the reasons this type electrode was one of the first to be used for welding high-tensile steels that were to be subsequently heat treated. It requires a 600° F minimum preheat and interpass temperature, generally followed with a heat treatment after welding and before cooling. It requires a relatively high tempering temperature (800–1000° F) to develop sufficient ductility and toughness; therefore, the maximum tensile strength that can be developed is around 190,000 psi.

Ultra-High-Strength Weld Metal

The development of ultra-high-strength steels for the aircraft industries has made rapid strides forward in the recent years and it is perhaps now on the threshold of its greatest advances since the beginning of supersonic speed of travel.

As a result of this great activity, three rather sharply defined ultra-high-strength brackets are in use today, namely: 220,000–240,000 psi, 240,000–260,000 psi and 260,000–280,000 psi, and at least ten other steels are under investigation with tensile strengths varying between 280,000 to 340,000 psi.

As far as we have been able to learn, there have been no other reports of research or developments published on electric-arc-welding electrodes for the welding of these ultra-high-strength steels. Of those steels in production, the use of resistance and pressure welding techniques are being used in fabrication.

In August 1954 our laboratory undertook a contract with the Bureau of Aeronautics, Airborne Equipment Division, Materials Branch (AE-415) to develop covered arc-welding electrodes capable of matching the tensile strength of these ultra-high-strength steels. Our paper[7] "Ultra-High-Strength Weld Metal with Low-Hydrogen Electrodes" contains some part of the results given in our final report to the Bureau of Aeronautics of this investigation together with data obtained since that time. Six different types of weld-metal composition were developed to match the properties of these ultra-high-strength steels now in use and those under investigation. The results were obtained over a three-year period during which approximately 150 weld metal compositions were investigated. They were classified into the six types according to the similarity of chemical composition to the ultra-high-strength steels for which they were developed. Table 4 gives typical weld-metal compositions and mechanical properties of these six types.

The weldability of all six types is very similar and typical of the low-hydrogen iron-powder types with a globular metal-arc transfer. They have an easy slag removal, smooth bead appearance and a good operator appeal because of their steady, smooth arc characteristics.

The basic coating composition used in the formulation of these electrodes enabled us to match practically any alloy-steel composition with weld metal, and the properties after heat treatment were similar to those of the steel it matched.

Several variations of titania- and lime-type coating compositions were used in these developments and to point out the differences is beyond the scope of this paper. It suffices to say that both types with many variations between have been and are being used successfully. The author does feel, however, that brief mention of the use of sponge iron powder in the coatings should be included, due to the increasing pop-

Table 4—Typical Analysis, Tensile Strength and Elongation of the Six Types of Ultra-High-Strength Weld Metals Heat Treated for Service Application

	Chemical analysis, %							Tensile strength, psi	Elongation in 1 in., %
Type	C	Mn	Si	Cr	Ni	Mo	V		
A	0.26	1.30	0.80	3.0	1.70	1.20	..	255,000	10.0
B	0.30	1.00	0.60	3.0	1.80	0.80	0.2	260,000	9.0
C	0.34	0.94	0.70	0.80	1.90	0.40	..	280,000	6.0
D	0.40	0.92	0.85	0.75	...	0.35	..	280,000	10.0
E	0.35	0.84	1.62	0.75	1.60	0.35	..	275,000	10.0
F	0.40	0.69	0.94	5.0	...	1.30	0.5	268,000	9.0

Table 5—Grain Size and the Effect of Tempering on the Bending Properties, All-Weld-Metal Tensile Strength and Hardness of Five Types of Ultra-High-Strength Weld Metals (4340 Steel Used as Base Metal)

Electrode type	*Formula no.*	*ASTM std. grain size*	*Tempering temperature, ° F*	*Transverse bending properties*		*All-weld metal tensile strength, psi*	*Rockwell C hardness*
				Angle of bend, deg	*Location of fracture**		
A†	BA75	4–7	500	38	W.M.*	250,000	48
			900	30	F.Z.	225,000	46
			1100	180	No fracture	152,000	32
C†	BA91	9	450	26	W.M.	270,000	51
			700	5	F.Z.	220,000	46
			800	30	W.M.	206,000	44
			900	55	W.M.	185,000	39
			1000	180	No fracture	160,000	34
D†	BA115	9	450	180	No fracture	275,000	53
			600	30	W.M.	225,000	47
			800	180	No fracture	200,000	43
E‡	BA120	6–9	450	8	F.Z.	287,000	54
			700	50	B.M. in H.A.Z.	245,000	48
			900	180	No fracture	208,000	41
F§	BA127	7–8	1125	...	...	266,000	52
			1175	134	...	242,000	46
			1200	55	Flaw in weld	210,000	40
	BA124	3–5	1050	3	...	250,000	51
			1100	5	...	236,000	49
	BA125	2–5	1050	35	...	252,500	51
			1100	180	No fracture	230,000	48
4340† steel		9	450	34	...	267,000	52
			700	145	...	220,000	46
			900	180	No fracture	180,000	39

* W.M., weld metal; B.M., base metal; F.Z., fusion zone; H.A.Z., heat-affected zone.
† 1550° F, oil quench.
‡ 1600° F, oil quench.
§ 1825° F, air quench and longitudinal in place of transverse bend.

ularity of these electrodes in the market today.

Early in the investigation of the Bureau of Aeronautics research contract, this laboratory discovered that both the lime- and titania-type coverings could be used satisfactorily for alloying the weld metal through the coating. As the project progressed and the interest in the iron-powder additions to the coating increased, lime-type coatings took preference over the titania type.

Electrode coatings using large quantities of iron powder for the lower-tensile weld metal proved advantageous over the conventional type primarily due to their increased weld-metal deposition rate. The principal function of the iron powder is to enable higher welding amperages to be used and to enable the designer to increase the built-in arc voltage of the electrode, both of which increase the weld-metal deposition rate. The iron powder, not being a part of the welding circuit except in the immediate vicinity of the arc, cools the weld metal as it melts in the molten puddle thus preventing its overheating and attendant difficulties. Where the alloys are added through the electrode coatings, they function similarly to that of the iron powder and thus the basic coatings developed for iron-powder low-hydrogen coating were found to be more desirable for these ultra-high-strength electrodes than the original ones. While fast deposition rates do not have the same importance for the high-tensile weld metal as they do in the low-tensile structural welding employed in our mass production economy, it is still a desirable characteristic of an electrode, providing the other properties are not sacrificed to obtain it.

The following properties were investigated on most of the six types of weld metal: Transverse and all-weld metal tensile and yield strengths, ductility, hardness, bending properties, toughness as measured by the Charpy V-notch impact, Jominy hardness, grain size determination, and the Lehigh restraint cracking tests. Most of them were made on the weld metal tempered over a wide range of temperature.

Types C and D weld metal seemed to have the best properties at the ultra-high-strength level tempered in the 400–500° F range, Types A and B were best in the 500–700° F range, Type E in the 600–800° F and Type F at 1050–1200° F tempering range.

Table 5 gives the grain size and the results of tempering on the weld-metal tensile strength, hardness and bending properties.

The angles of bend for the transverse welds of types A, C, D and E, using 4340 base metal and the longitudinal bend of Type F, varied between approximately 26 to 180 deg at the recommended tempering tempera-

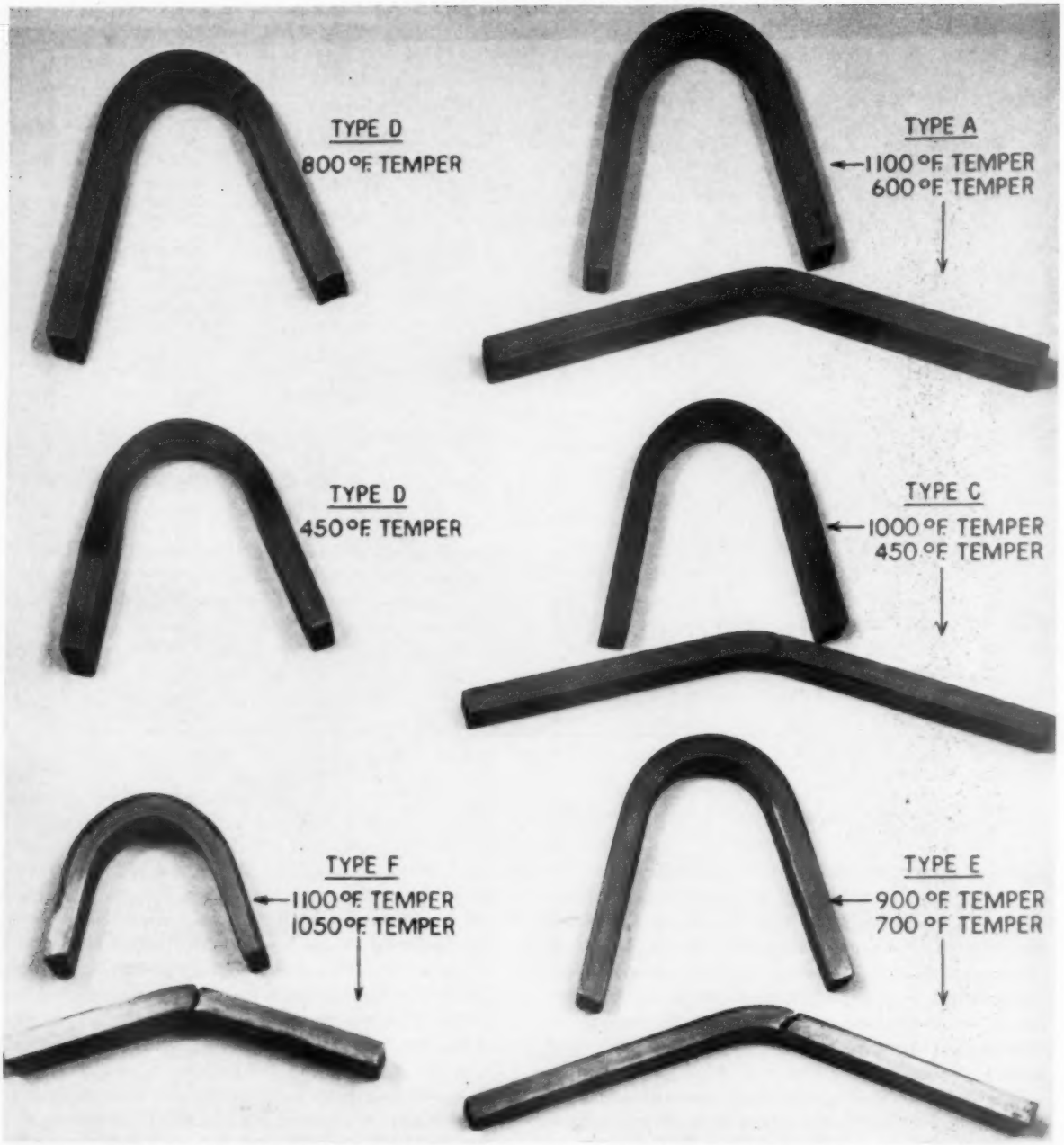

Fig. 11 Guided-bend tests of ultra-high-tensile weld metals at indicated tempering temperatures—bend radius 2T

tures. Figure 11 shows the transverse bending angles obtained on Types A, C, D and E at their upper and lower tempering temperatures using 4340 base metal and Type F longitudinal bends at two tempering temperatures. Longitudinal bends were made on Type F weld metal because its tensile strength was so much greater than 4340 steel at these high tempering temperatures (1050-1200° F) that all the bending of the transverse weldment took place in the base metal or fusion zone and none in the weld itself.

All the bending tests were made using a standard guided-bend jig with a $^3/_4$-in. mandrel making a bend radius of 2T. Had a $1^1/_4$-in. mandrel (bend radius of 3.3T) been used as permitted by the pressure-vessel codes for high-tensile steels, greater bending angles would have been obtained, particularly with those that broke in the fusion or heat-affected zone.

Better ductility on many of these specimens could have been obtained with a more elaborate heat-treating process, such as longer and/or more cycles of tempering, but the data obtained suffices to show the feasibility of using these electrodes under service conditions.

The surface hardness as measured by the Jominy method (Fig. 12) was greatest for Type E and lowest

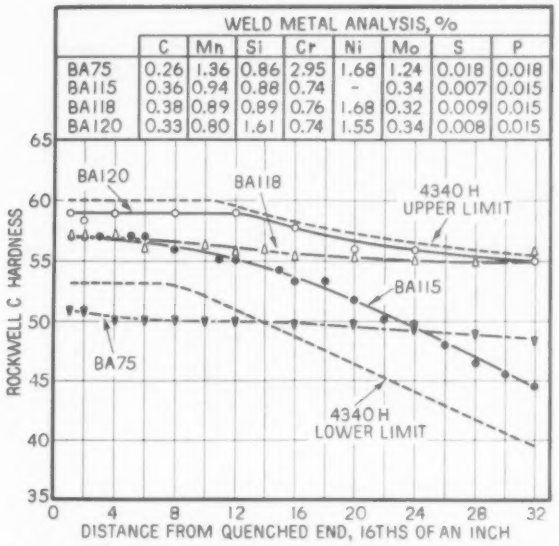

Fig. 12 Jominy hardenability tests of four experimental ultra-high-strength electrode weld metals

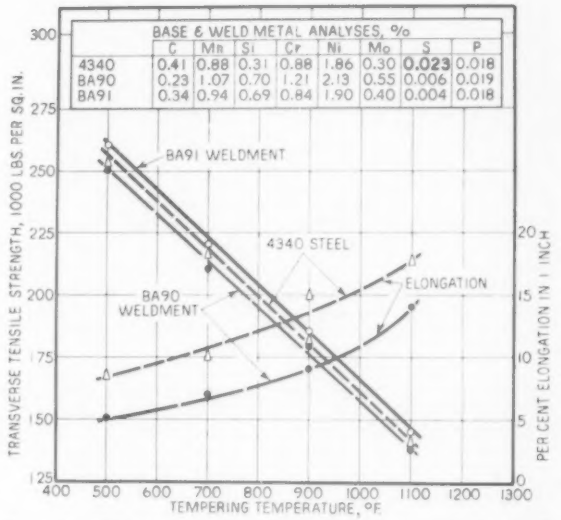
BASE & WELD METAL ANALYSES, %
C Mn Si Cr Ni Mo S P
4340 0.41 0.88 0.31 0.88 1.86 0.30 0.023 0.018
BA90 0.23 1.07 0.70 1.21 2.13 0.55 0.006 0.019
BA91 0.34 0.94 0.69 0.84 1.90 0.40 0.004 0.018
BA91 WELDMENT
4340 STEEL
ELONGATION
BA90 WELDMENT
TRANSVERSE TENSILE STRENGTH, 1000 LBS PER SQ IN.
PER CENT ELONGATION IN 1 INCH
TEMPERING TEMPERATURE, °F

Fig. 14 Effect of tempering on the transverse tensile strength and elongation of weldments made with BA90 and BA91 electrodes in 4340 steel

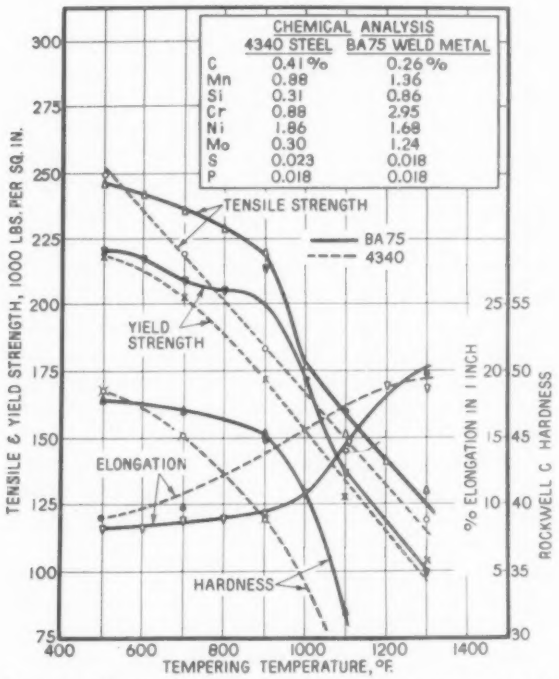

Fig. 13 Effect of tempering on the tensile strength, yield strength, elongation and hardness of BA75 weld metal and 4340 steel

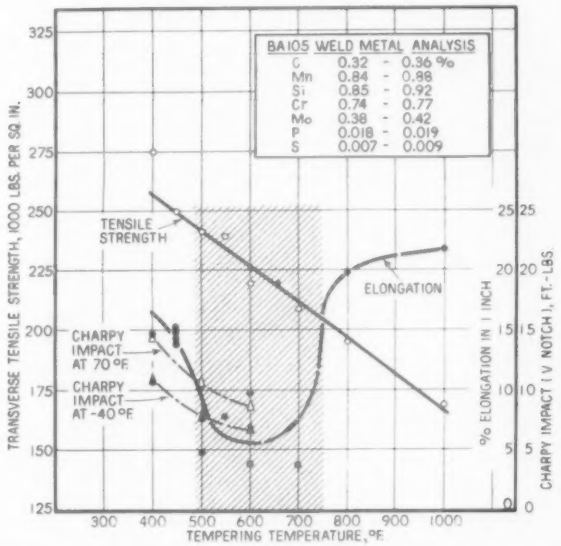
BA105 WELD METAL ANALYSIS
C 0.32 - 0.36 %
Mn 0.84 - 0.88
Si 0.85 - 0.92
Cr 0.74 - 0.77
Mo 0.38 - 0.42
P 0.018 - 0.019
S 0.007 - 0.009
TENSILE STRENGTH
ELONGATION
CHARPY IMPACT AT 70°F
CHARPY IMPACT AT -40°F
TRANSVERSE TENSILE STRENGTH, 1000 LBS. PER SQ. IN.
% ELONGATION IN 1 INCH
CHARPY IMPACT I V NOTCH I, FT.-LBS
TEMPERING TEMPERATURE, °F

Fig. 15 Effect of tempering on the transverse tensile strength, elongation and impact strength of BA105 weld metal used with 4340 base metal

for types A and B where the carbon content was the lowest. At depths $^3/_4$-in. and greater the hardness of types A and B fell well within the H-bands of 4340 steel. Type F weld metal was not measured.

Figures 13, 14, 15 and 16 show the effect of tempering on the tensile strengths and ductility of Types A, C, D and E, respectively. The curves of Types C, D and E show a proportional decrease of tensile strength with increased tempering temperature comparable to 4340 steel, where with Type A the tensile strength decreases only slightly with increasing tempering temperature up to approximately 900° F. Above 900° F the tensile strength falls off proportionally with increasing tempering temperature. The ultimate tensile strength values with elongations 6.0% and above among the six different types varied between approximately 250,000 psi for Type A to 300,000 psi for Type D. The elongation varied between 6.0 to 15.0%.

Table 6 gives the effect of tempering and testing temperatures on the Charpy V-notch impact strength of these ultra-high-strength weld metals. The impact

Table 6—V-Notch Charpy Impact Properties of 4340 Steel and Five Ultra-High-Strength Weld-Metal Compositions Typical of Each Type Studied in This Investigation

Type	Formula no.	Tempering temperature, ° F	Weld metal analysis, %								Tensile strength, psi	Average Charpy impact (V-notch), ft-lb			
			C	Mn	Si	Cr	Ni	Mo	V	P	S		70° F	0° F	−40° F	−60° F
A	75	500	0.26	1.36	0.86	2.95	1.68	1.24		0.018	0.018	250,000	9.0	8.0	7.0	...
		700										235,000	10.0	9.0	8.0	...
		800										230,000	8.5	8.0	7.0	...
		900										220,000	11.0	8.0	6.5	...
		1100										160,000	30.0	23.0	20.0	...
		400*										255,000	13.8	...	10.2	8.0
		600*										240,000	14.6	...	11.4	11.0
D	105	400	0.30	0.87	0.87	0.75	...	0.40	...	0.018	0.007	255,000	15.0	...	11.8	...
		450	0.36	0.84	0.92	0.97	...	0.34	...	0.019	0.007	245,000	16.0	14.0	8.0	...
		500	0.30	0.87	0.87	0.75	...	0.40	...	0.018	0.007	240,000	11.0	...	8.0	...
		600										220,000	16.0	11.0	9.5	...
		800										195,000	19.0	15.0	14.0	...
C	91	450	0.34	0.86	0.77	0.81	1.91	0.40	...	0.013	0.009	265,000	16.0	13.5	13.0	...
		600										240,000	12.0	9.0	9.0	...
		800										210,000	19.0	11.5	10.0	...
E	120	450	0.33	0.80	1.61	0.74	1.55	0.34	...	0.015	0.010	275,000	8.0	7.5	7.5	...
		600										250,000	6.5	7.0	5.0	...
		800										230,000	17.0	6.0	12.0	...
F	127	1125	0.41	0.69	0.94	5.50	...	1.57	0.51	0.026	0.010	266,000	12.0	10.0	8.0	...
		1175										242,000	15.0	...	9.0	...
		1200										210,000	30.0	14.0	14.5	...
4340 steel	...	500	0.41	0.88	0.31	0.88	1.86	0.30	...	0.018	0.023	268,000	6.0	5.0	5.0	...
		700										220,000	7.0	7.0	7.0	...
		900										180,000	12.0	10.0	9.0	...

* Data received through private communication from Boeing Aircraft Co.

Fig. 16 Effect of tempering on the all-weld-metal tensile strength and elongation of BA120 and 4340 steel

values for Types C and D weld metal with the recommended 450° F temper was 16.0 ft-lb at room temperature and 13.0 and 8.0 ft-lb at −40° F. For Type A at 600° F temper it was 14.6 ft-lb at room temperature and 11.4 ft-lb at −40° F; Type E at 800° F temper was 17.0 ft-lb at room temperature and 12.0 ft-lb at −40° F; and for Type F at 1125° F temper 12.0 ft-lb at room temperature and 8.0 ft-lb at −40° F temperature.

Table 7 gives the results of the Lehigh restraint cracking tests and Fig. 17 shows a typical crack started in the root which did not propagate up through the weld.

The final proof of their practical worth as a tool and material for construction must be demonstrated under serviceable conditions. Since the cracking tendency of the weldment made under high restraint is the greatest problem generally encountered with the welding of high-carbon alloy metal, the results of the Lehigh restraint test should be an indicator of what can be expected in service application.

These results follow very much in line with our experience in making the various test bars throughout this investigation. Types A and B would sometime crack if allowed to cool to room temperature after welding be-

Fig. 17 Crack in Lehigh restraint test of Type A weld metal (6 in. restraint)

Table 7—Lehigh Restraint Cracking Tests on Five Types of Ultra-High-Strength Weld Metal Using 1-In. Thick Test Specimen

Electrode type	Formula no.	Preheat temperature, ° F	Contraction across weld, in. 6-in. restraint	Contraction across weld, in. 8-in. restraint	Cracking results up to 24 hr after depositing weld bead 6-in. restraint*	Cracking results up to 24 hr after depositing weld bead 8-in. restraint*	Remarks
A	BA75	450	0.012		Small crack		Small crack approximately 1/16 in. at root did not propagate through weld
		450				Cracked	Started to open up as its temperature dropped from 500 to 400° F
C	BA91	450	0.012		None		
		450		0.005		None	
D	BA105	400		0.005		None	
		200				Cracked	Cracked while cooling back to room temperature
		250	0.014		None		
		250				Cracked	No visible cracks 4 hr after welding but cracked full length of weld during night
	BA115	450	0.010		None		
		450		0.005		None	
E	BA120	450	0.008		None		
		450		0.004		None	
F	BA127	700			Cracked		Cracked when specimen cooled to approximately 200° F
	BA128	700				Cracked	Cracked when specimen cooled to approximately 200° F

* Restraint is indicated in terms of the uncut width of the specimen.

fore subsequent heat treatment. This behavior is indicated by the cracking of both the 6-in. and 8-in. restraint specimens as they cooled back to room temperature. The 6-in. restraint specimen only cracked a short distance at the root however and could not be seen until the weld was cross sectioned. This indicates that cracking can certainly be prevented if the weldment is not allowed to cool after welding before stress relieving or annealing. Type F always cracked regardless of the weld restraint if allowed to cool to room temperature after welding and before heat treatment but did not crack if stress relieved or annealed before cooling. Types C, D and E did not crack with a 450° F preheat on cooling back to room temperature after welding in either specimen. A 600° F preheat and interpass temperature is recommended for Types A and B followed

Table 8—Welding Conditions and Heat Treatment Used for the Six Types of Experimental Ultra-High-Strength Weld Metals Studied in This Investigation

Transverse weldments made with 1/2-in. thick 4340 base metal.
All-weld metal specimens made with 3/4-in. thick ASTM A7, A85 base metal with the scarfed edges buttered with 1/2-in. thick weld metal

Weld metal type	Size in.	Amperage	Preheat and interpass temperature, ° F	Normalizing temperature, ° F	Quenching temperature, ° F	Processing annealing temperature, ° F	Remarks
A and B, Mn-Cr-Ni-Mo and Mn-Cr-Ni-Mo-V	1/8	140	600	1600	1550	1300–1350	Weldments were not allowed to cool below preheat and interpass temperature before normalizing
	5/32	185	600	1600	1550	1300–1350	
	3/16	240	600	1600	1550	1300–1350	
C, Cr-Ni-Mo	1/8	140	450	1600	1550	1275–1300	Weldments allowed to cool to room temperature before normalizing
	5/32	185	450	1600	1550	1275–1300	
	3/16	240	450	1600	1550	1275–1300	
D, Cr-Mo	1/8	140	450	1600	1550	1250–1275	Weldments allowed to cool to room temperature before normalizing
	5/32	185	450	1600	1550	1250–1275	
	3/16	240	450	1600	1550	1250–1275	
E, Si-Ni-Cr-Mo	1/8	140	450	1700	1600	1275–1300	Weldments allowed to cool to room temperature before normalizing
	5/32	185	450	1700	1600	1275–1300	
	3/16	240	450	1700	1600	1275–1300	
F, Cr-Mo-V	1/8	140	700	*	1825†	1550 cool at 50°/hr to 1000° F	Weldments process annealed immediately after welding without dropping below 700° F
	5/32	185	700	*	1825†		
	3/16	240	700	*	1825†		

* No normalizing treatment. Weldments process annealed immediately after welding.
† Air quenched. All other test specimens quenched in oil.

by a stress relieving or process-annealing heat treatment and a 700° F min preheat followed by stress relieving or process-annealing heat treatment for Type F.

Thus these data indicate that these three Types, C, D and E, would be more foolproof and less troublesome in production than Types A, B and F because of their less cracking tendency.

Further work is desirable to determine the minimum level of restraint to develop cracks but the work done so far indicates that all six types can be used under service conditions if recommended preheats, interpass temperature and postheat treatments as given in Table 8 are followed out.

It is difficult on the basis of the tests made to select any one of these types as the best. An understanding of the properties desired must first be obtained and then a more intelligent selection can be made. Each type made has an application suitable for the particular service required.

The results show, however, that practically all the ultra-high-strength steel compositions can be matched with weld metal. Furthermore, it is believed that enough data have been obtained to show that it is possible to use these electrodes under service conditions to fabricate these steels.

Summary

1. Weld metal above 100,000 psi development commenced with the introduction of low-hydrogen electrodes during World War II.

2. Variable moisture contents of the coating caused erratic and unpredictable results with the first high-tensile lime-ferritic commercial electrodes.

3. Moisture controls in the coating of low-hydrogen electrodes purchased for military purposes were first established by the Navy Department, Bureau of Ships, as a result of the Navy-NEMA Committee work in the development of the nickel-molybdenum-vanadium high-tensile electrodes MIL-230-16 and MIL-260-15.

4. Results of an investigation on the effect of moisture in the coatings of Types MIL-230-16 and MIL-260-15 electrodes on the welding of armor plate $1^1/_2$-in. thick showed moisture to be an important factor in causing weldment failures. Moisture contents above 0.30% resulted in weldment failures due to cracking, primarily in the fusion zone. When electrodes with moisture contents 0.20% or lower were used, sound weldments were made under similarly stressed conditions. Electrodes having moisture contents in the approximate range 0.20–0.30% were borderline in making sound weldments under these same conditions. Other factors such as preheat, operator technique, surface profile of the weld metal, and factors that affect the merging or washing up of the weld metal on the side walls of the scarfed joint are all important in making sound weldments using high-tensile electrodes.

5. Electrodes that have absorbed a harmful amount of moisture can be reconditioned for use by using the recommended redrying procedure.

6. The nickel-molybdenum-vanadium electrodes MIL 260-15 developed for use with little or no preheat were found to develop temper brittleness when stress relieved or tempered in the range of 900–1200° F.

7. Development of high-tensile heat-treatable electrodes for cast armor repair to overcome the temper brittleness of the nickel-molybdenum-vanadium types resulted in three types primarily, i.e., manganese-molybdenum, chromium-molybdenum, and manganese-chromium-nickel-molybdenum.

8. Development of high-tensile heat-treatable electrodes between 125,000–200,000 psi for aircraft fabrication resulted in five types primarily, two of the types used in cast armor repair, two others of a manganese-chromium-nickel-molybdenum-vanadium higher in alloy and tensile strength than those used in cast armor repair, and the standard Type 502.

9. Six different types of ultra-high-strength weld metal were developed and their compositions and properties including tensile and yield strengths, ductility, hardness, transverse and longitudinal bending properties, Charpy V-impact, Jominy hardness, grain size, and Lehigh restraint cracking tests are given.

Two types showed best ultra-high-strength properties at 400–500° F temper, two at 500–700° F, one from 600–800° F and one from 1050–1200° F tempering temperatures.

Results of the ultra-high-strength weld-metal development show that practically all the compositions of the ultra-high-strength steels now in use and those under investigation can be matched with weld metal.

Acknowledgments

Realizing that this honor accorded me is essentially a recognition of the work of the Research Laboratory of the Harnischfeger Corp., I accept it on behalf of all my colleagues and gratefully acknowledge the special contributions of W. G. Rinehart who assisted in obtaining these data and writing it up, to K. P. Johannes for preparing all the illustrations and rendering valuable assistance in many other ways, to D. C. Helton for his suggestions and interest, to M T. Roberts and his laboratory staff for their valuable assistance in preparing and testing impact specimens, radio- and microphotographs, and grain size determinations, and to the Ordnance Corps, U. S. Army, and the Bureau of Aeronautics, Airborne Equipment Division, for their permission to publish some of the data we obtained in research contracts sponsored by them. We also are indebted to the Harnischfeger Corp. management for their encouragement and permission to publish this work.

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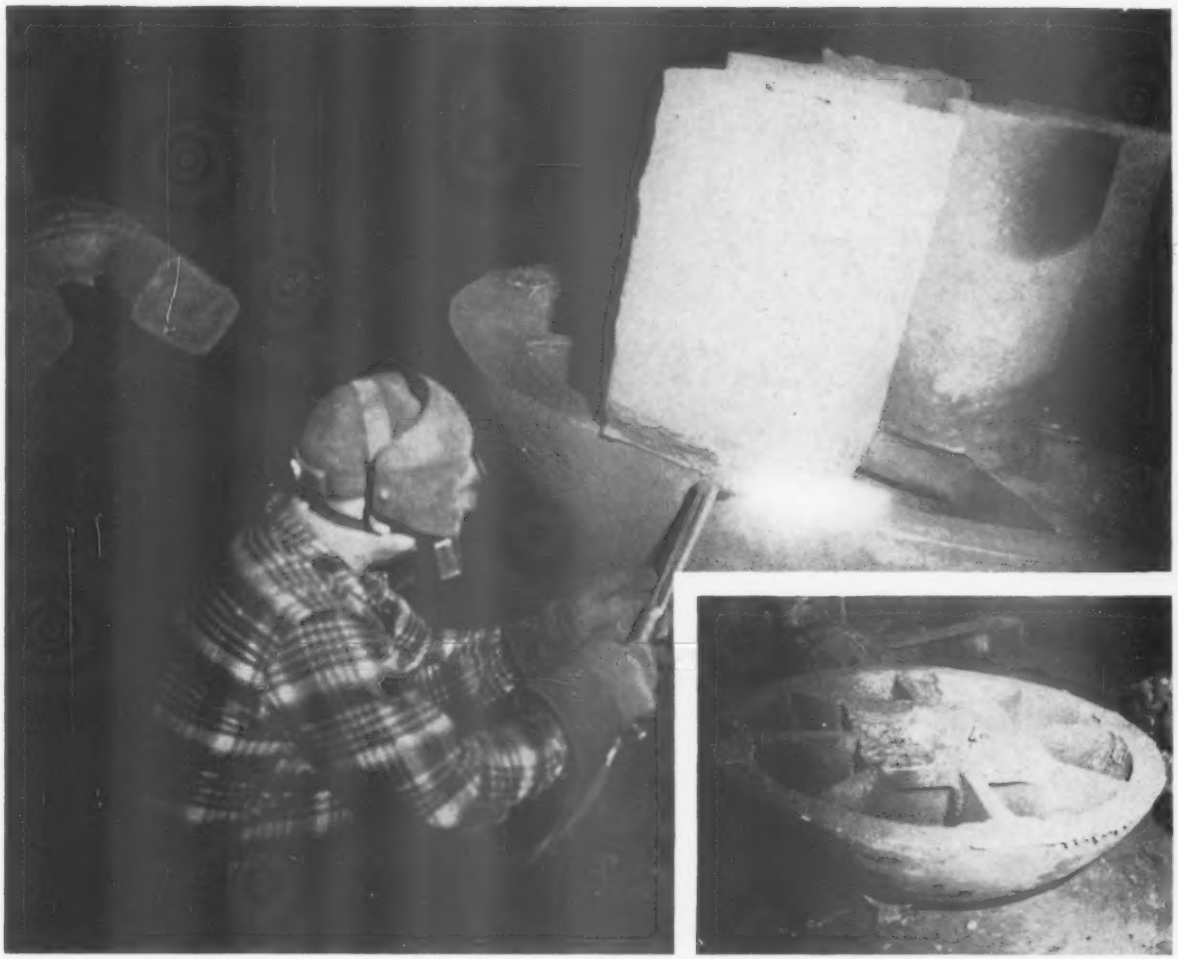

Fig. 1 Manual oxygen cutting to remove feeder heads from steel casting

WELDING AND RELATED PROCEDURES ENCOUNTERED IN A MODERN STEEL FOUNDRY

Paper shows contribution being made daily to industrial progress by an up-to-date foundry through diverse application of welding, its related processes and equipment

BY SAMUEL W. GEARHART, JR.

SYNOPSIS. Factors relating to the complementary aspects of welding processes and foundry products have been little discussed. A great deal of credit for the increased confidence of casting users is due to the technological growth of welding. This paper shows the interdependence of the welding and the foundry industries. The uses of related procedures in the conditioning of steel castings are discussed and are illustrated in their application. Welding processes have been adopted with new emphasis in the foundry, for (1) improving casting quality, (2) simplification of casting design through fusion joining processes, and (3) incorporation of castings in welded structures. Examples are shown, limitations are discussed, and engineering aspects are considered.

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Introduction

Welding is a natural process in the manufacture of carbon and low-alloy steel castings, but little emphasis

has been placed on the importance that welding plays in the operation of a modern steel foundry. The AMERICAN WELDING SOCIETY, as one of its major contributions, has promoted and advertised welding's success in the application of fusion joining processes to engineered components. This has been largely accomplished through the interchange of welding technology and experience among society members and industry at large. Our efforts here are to show the contribution being made daily to industrial progress by an up-to-date foundry through diverse application of welding, its related processes and equipment.

With the ever-increasing confidence of customer and supplier, unnecessary and obscure restrictions regarding the proper repair of castings have been relaxed. By overcoming "old-school" defections, foundries have been able to concentrate on: (1) processes and techniques of welding which now assure sound cast products (repaired by welding); (2) diversification of foundry operations; and (3) savings in cost, time and materials in the manufacture of products through cast-weld and composite structure weldments. As founders, first, and welders, second, our needs must be anticipated along the line of new developments in the welding industry if founders are to continue to meet the challenges of the present day's highly competitive economy.

The Challenge—Past, Present and Future

Excuses for not using steel castings are time-worn and will not be contested here. Castings which were formerly treated as weakened structures because of repair welds to correct questionable soundness are gaining acceptance through the open discussion of inherent defects in them and their repair by welding. The continued growth of the steel casting industry and the emergence of higher quality and lower cost products from their production has been met with an unremitting clamor for its competition to the fabrication shop. As we disclose the wealth of welding opportunities and applications encountered in the foundry, these claims will be shown unsubstantiated. Know-how in the application of welding processes as illustrated herein cite for the welding equipment supplier, welding engineer and welder, ways in which the foundry has contributed to the industrial progress of welding. The interdependence of the welding and founding industries as discussed will be readily apparent to the alert. We offer this as food-for-thought to the skeptic. The latter rise from obscurity from time to time, hindering progress as they go. Their passive approach to welding problems is familiar to all who want to weld.

The prudent use of fusion joining processes is, in part, responsible for increased acceptance of steel castings. Reliable producers have found that advances in foundry processes and requirements are closely allied to advances in welding. This use of welding is increasing because of foundry diversification to cast-weld and composite weldment structures. Many of you have it within your power to specify the use of welding in designs, details and specifications; as reliable engineers and producers, you can help in the accomplishment of this expansion. Applications of welding and its related processes will grow unhindered by ingenious approach above and beyond restrictive standardization.

Conditioning of Steel Castings

In the systematic order of casting conditioning, two major cutting processes are used for gate, feeder head and pad removal. Essentially, these methods rely on oxidation and are broadly identified as oxygen cutting and powder cutting.

Manual Oxygen Cutting

The oxygen-cutting process is incorporated in both manual and fully automatic setup. Manually-operated oxyacetylene cutting torches (Fig. 1) permit maximum freedom for the oxygen cutter. His approach to the

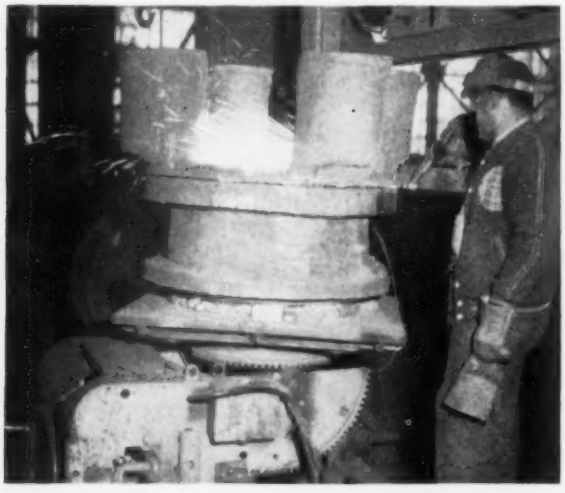


Fig. 2 Machine oxygen cutting to remove feeder heads and circular cutting strip

Fig. 3 Manual powder-oxygen cutting to remove large feeder heads

job is limited only in so far as his safety and comfort are assured. Handling of castings is reduced to a minimum by selective positioning once the casting has been brought to the cutting floor. As major protuberances are removed, the operator finds the cutting tip equally adaptable for removing fins and other unwanted projections. The oxygen cutters work to layout lines and have the ability to follow very closely casting contour. Where burnt-on molding sand or core sand is encountered, the flame is frequently diverted and may cause pocketing or undercutting. This is the major limitation to this equipment. The oxygen lance is used to supplement oxygen cutting where large cross-sections are required to be cut during feeder-head removal or scrapping.

Automatic Oxygen Cutting

In conjunction with a motor-operated revolving and tilting welding table, universal positioning of an oxygen cutting torch provides a unique arrangement for special work (Fig. 2). The extra set-up time and careful alignment required in these instances is generally off-set by a uniformity of cut to close tolerances and with smooth drag on the sides of the kerf. This requires little chipping or grinding; frequently, only blast cleaning is needed to remove adhering slag. This arrangement is adaptable to castings with circular heads or for removing cutting strips, as illustrated.

Manual Powder-Oxygen Cutting

The powder-oxygen cutting process (Fig. 3) involves metal powder being automatically injected into an oxyacetylene flame to increase the flame's heat and to speed the cutting action. Application of this procedure by manual operation is two-fold. Next to removal of large cross-section feeder heads, greatest appreciation comes from flame washing to remove highly refractory molding sand, particularly where it is tightly adherent and in areas that would be time consuming and difficult to reach by mechanical methods (such as chipping). The limitation in this respect is narrow, deeply cored holes which cause flame and molten materials to be blasted back on the operator and equipment. Flame washing with powder is used to a lesser extent for pad removal, and then only when extensive areas on the casting surface are involved. In many instances, finishing operations such as chipping and grinding are unnecessary because of the ability to control cutting action very close to pattern contours.

Fig. 4 Carbon-arc-compressed-air cutting to remove casting projections

Oxygen Torch Gouging

Other uses of hand-operated oxygen cutting equipment are in removing metal for alterations, as well as in maintenance and repair. Using gouging tips on the oxyacetylene torch, the unit becomes the primary means for gross defect removal in the repair of steel castings. The rapidity and ease with which metal is removed from deep cavities is noteworthy. The equipment has sufficient flexibility to be adaptable to unusual casting configurations and openings. This same gouging torch is used for removal of tack welds, and for preparation of the underside of first pass deposits in double-welded butt-joints.

Carbon-Arc Cutting

Adaptation of carbon arc-compressed air cutting techniques has been more recent and has shown many advantages. Essentially this is an electrical arc-melting process whereby molten metal at the carbon electrode to casting arc is blown away by compressed air directed parallel to the electrode by a specially-constructed electrode holder. Carbon-arc cutting is used particularly for surface conditioning in highly restricted areas, as in Fig. 4, where contouring and filleting are essential in the ultimate design. Pads, and other unwanted protuberances are oxygen cut to within $^1/_4$ in. to $^3/_8$ in. of casting finish dimension; carbon-arc washing to the final requirements is rapid with a high rate of metal removal. The completed surface is quite smooth, and in many instances carbon-arc cutting supplants later chipping and grinding operations. Carbon-arc-compressed air cutting has replaced back-chipping of the underside of first-pass welds in double-welded butt joints. An expanding use is the application of carbon-arc cutting for defect removal, principally shallow surface cracks and tears. Here the operator is able to control groove openings very closely, eliminating excessive welding. Joint openings are produced which require little grinding of sides and roots prior to welding. Much larger cavities are encountered where chip and grind methods of defect removal are used because greater opening is needed to properly manipulate the equipment. The competent carbon-arc cutting operator can observe the removal of defects. This progress is not readily apparent when mechanical methods, such as chipping, are used. Grinding, to remove surface disturbed layers of metal, and frequent use of magnetic particle inspection, usually supplement visual examination in the latter instance. Rate of metal removal is incomparable

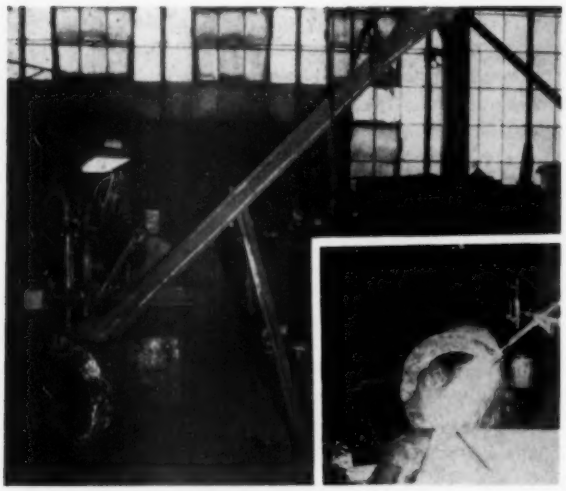


Fig. 5 Stationary machine oxygen cutting of weld joint bevels on large strut castings

Fig. 6 Alignment of strut castings for tack welding after machine oxygen cutting

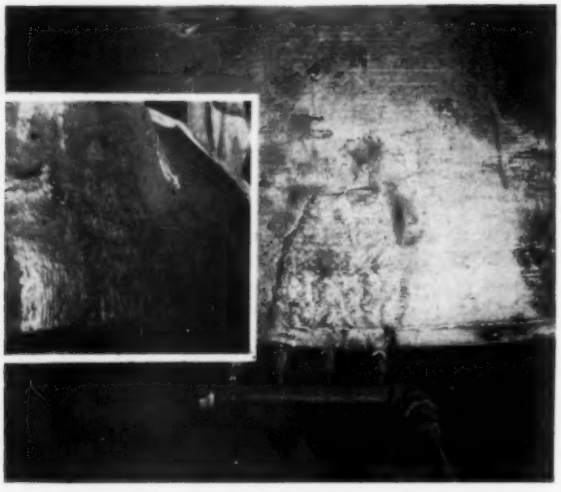


Fig. 7 Completed manual shielded-metal-arc weld and condition following carbon-arc compressed-air washing

Fig. 8 Semiautomatic submerged-arc welding of ship propulsion shaft strut castings

where high-carbon steel and alloy grades with attendant higher hardnesses are encountered. In these instances, the ordinary precautions of preheat and postheat are relied upon and have successfully eliminated any cracking problem from carbon-arc cutting these hardenable steels.

Copper-sheathed carbon electrodes, $^1/_2$ in. and $^3/_4$ in. diameter are used. Carbonization and subsequent cracking have been guarded against by familiarization of operators on the need for maintaining a full air stream while cutting. Thus carbon pickup is held to a minimum.

Oxygen-Cutting Machine

Stationary oxygen-cutting machine equipment finds many uses in the foundry. Its principal use is the widely known multiple-torch cutting of both regular and irregular shapes for use in machinery-type weldments. A unique adaptation of this equipment is illustrated in Fig. 5. High quality and accuracy of these machine oxygen-cut bevels has eliminated what was formerly a very costly handling and machining operation on large castings. As shown, little effort is required to produce bevels automatically and controlled to close tolerances of specified groove dimensions. This assures accurate fitup of mating sections—the two barrel halves in the parts illustrated. These sections are fusion joined to make a ship propulsion-shaft strut. Figure 6 shows the accuracy achieved by oxygen beveling. The parts are aligned by templets and by plumbing. Following tack welding of the parts as shown, the castings are positioned for final welding.

Special Equipment

The foundry also makes wide use, as is well-known, of large size oxyacetylene welding torches and gas-air

heating heads. These are used in conjunction with pressing and straightening operations, whereby the heating is followed by mechanical pressing. Otherwise, reliance is made on flame straightening whereby contraction of locally heated areas on cooling results in parts being pulled to the side of application of heat.

In the foregoing we have illustrated the use of equipment related to the welding industry as encountered in the foundry. Applications, both unusual and widely accepted, have been used to demonstrate reliance on these methods to assure higher quality cast products at lower cost.

Welding of Steel Castings

Direct application of joining techniques in the modern foundry extends from the repair of the most minute surface blemish through major defect removal and weld repair of steel castings. Beyond this are applications involving joining processes resulting from simplification of casting design and foundry practice. These are encountered in cast-weld construction and in the incorporation of castings with wrought products in composite structures. The equipment also fills a natural need in the maintenance of buildings and manufacturing facilities. Manual shielded-metal-arc, automatic submerged-arc and semiautomatic submerged-arc welding are the most frequently used processes. Specialized processes of exothermic welding and metallizing have been utilized from time to time.

Adhering closely to the recommendations of the AMERICAN WELDING SOCIETY, manual welders are qualified to minimum standards in flat, vertical and horizontal position welding. Welding procedures have been developed covering the standard group of analyses and mechanical property ranges encountered in daily casting production. New analyses and metallurgical factors are considered as these problems arise, as are the governing codes and specifications of agencies of the Federal Government, other engineering societies and customer requirements. Welding operators and their procedures are similarly qualified.

Casting Repair—Search and Weld

A great deal of time is consumed in the rework of defective castings. These casting discrepancies are peculiar and inherent to the foundry industry. The casting repair procedure begins with the selection and execution of a search technique. Because of the increased cost of re-work, technicians are employed who are competent in the selection of the inspection method and interpretation of results. Customers, through cooperative effort, are becoming more specific in their quality requirements, are designating highly stressed areas, and are detailing special service requirements. As you, we are still waiting for the first usable and definitive statement regarding the term, "injurious defects."

Search methods most frequently used are visual inspection, magnetic particle, radiography, trepanning, liquid penetrant and pressure tests. Ultrasonic and leak tests have not been adopted. Applied concurrently with defect removal by the methods described earlier, complete removal of the defective area is assured. We hasten to point out that these methods are not only applied as a means toward meeting customer requirements, but nondestructive testing has become a tool within the foundry to cure and prevent high rejects, excessive repair and unnecessary scrapping.

With complete removal of the defect, selection of the repair procedure is fundamental. Welders have been proven competent in ordinary classes of electrodes, and more recently particular attention has been given to the iron-powder low-hydrogen type electrodes. These have been adopted for more and more extensive use in casting repair procedures where arc time is high. This follows the inherent characteristics of castings to show segregation and to contain higher quantities of carbon, for strength, manganese and silicon, for deoxidation. Their effect is minimized and adequate welds are assured by the low-hydrogen coating. These welds are made with less difficulty and faster than with the conventional low-hydrogen electrodes heretofore used. Weld test plates and radiographic examination of actual repair areas attest to the proficiency of the welders and adequacy of the deposited metal. Welders have shown favorable response and acceptance. Improved quality of our welds is believed fundamentally associated with this appeal. Retained slag is minimized as a condition for weld repairs. Higher deposition rate is expected to reflect in cost savings as further records are accumulated.

In so far as possible, castings are positioned for greatest deposition of weld metal in the down hand position. Larger defects are repaired using semiautomatic submerged-arc processes. Otherwise, manual shielded-metal-arc welding is used. Preheat and postheat requirements are strictly adhered to. Major welds are made subject to customer approval and may be succeeded by the complete heat-treat cycle to develop base-metal properties. An example of a typical manually-repaired area is shown in Fig. 7. The inset illustrates the condition of the surface after removal of weld reinforcement and ripple by carbon-arc washing technique. Surface grinding is thus reduced to a minimum. Manual shielded-metal-arc welding, using all classes of electrodes, is also used in short welds on odd shapes, nonrepetitive in nature and on cast-weld and composite structures.

Semiautomatic Submerged-Arc Welding

In addition to repair welds, the semiautomatic submerged-arc process is adapted to other joining problems. Recalling Fig. 6, showing the tack-welded strut castings, Fig. 8 illustrates how the semiautomatic submerged-arc technique, demonstrated by the operator, is used to complete this joint. The strut arms are inverted and the operator works from a scaffold when welding the diametrically opposite groove on the strut barrel. This is a repetitive type job, subject to major dimensional changes from basic design and size. However, the welds are of considerable depth and result in much

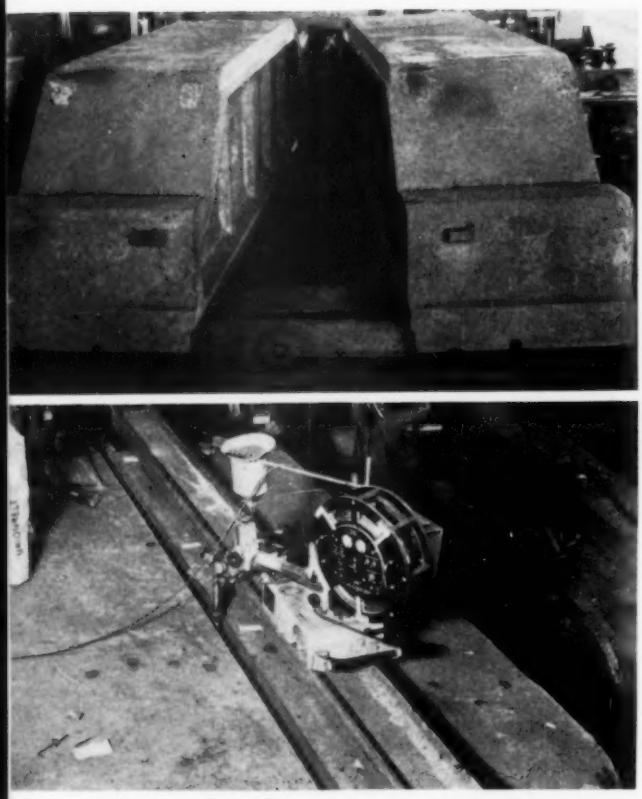


Fig. 9 Automatic submerged-arc welding of beam castings

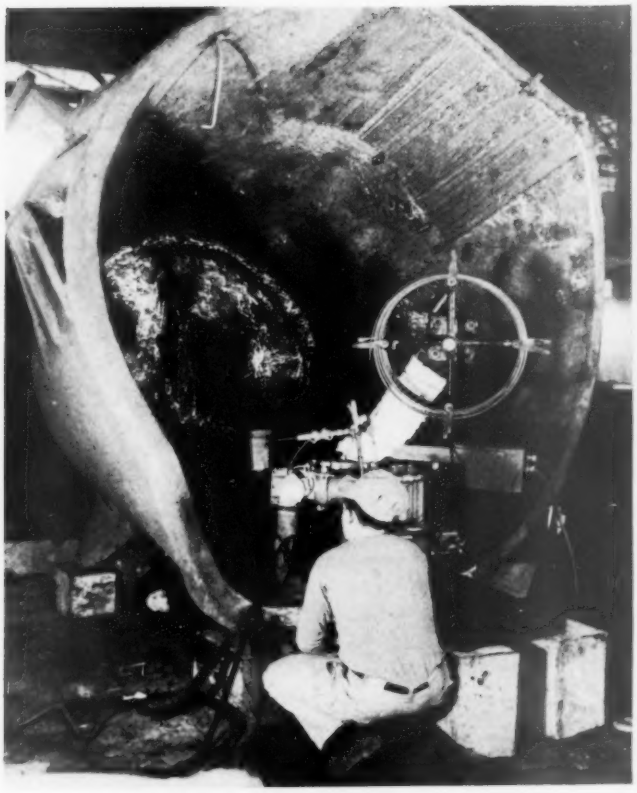


Fig. 10 Overlay deposition by automatic submerged-arc welding on ladle casting

accumulated footage of deposit as repetitive short welds. Manual guiding and simplest fixturing make this an ideal condition and application. Irregular shapes, too difficult to position under an automatic head, are also welded by this technique.

Automatic Submerged-Arc Welding

Fully automatic submerged-arc welding was selected to join the castings shown in Fig. 9, top. Note that incomplete penetration joints were required and the U-butt joint was machined, being incorporated in the facing operation on the planer. The advantages of high-speed, high-quality weld deposit and low labor cost are primary considerations.

Cladding or overlay deposition by the automatic submerged-arc process in the foundry is shown in Fig. 10. Here an overlay is being deposited on the bottom and spouts of a large matte ladle to prevent erosion. Contours of the lip and edges of the spouts are finished by manual shielded-metal-arc welding, resulting in the final condition shown in Fig. 11.

Exothermic fusion and metallizing are not illustrated, since these have been used principally as salvage techniques.

Cast-Weld Design

A constant challenge to the steel foundryman has been the increasing size and complexity of design signifying the improbability of casting. Casting quality is made or doomed in the design stage. Hence, we view this situation through simplification of casting design by an approach to these problems from the cast-weld point of view. Adaptation of welds to casting designs has been a gradual transition in the foundry. Nothing so revolutionary has occurred as in all-fabrication weldments during the war, when designs were necessarily flexible to circumvent material shortages. We will not detail the advantages or disadvantages of all-cast, cast-weld, composite welded or all-fabricated weldments; suffice to say, that there is increased recognition of cast-weld design.

Where considerations of weight, design and cost make it practically impossible to produce a piece as a single, quality casting; the unit is divided into castable segments, and these segments are welded together. A well-engineered breakdown of this sort results in simplified castings of improved quality which are relatively easy to produce. The approach to this design requires cooperation between foundry engineers, product designers and welding engineers to assure everything possible is done for product improvement. Cast-weld design makes possible the production of large structures which would have limited availability as single castings because of foundry limitations (molding space, melting capacity, handling facilities,

Fig. 11 Completed overlay on bottom and spouts of ladle casting

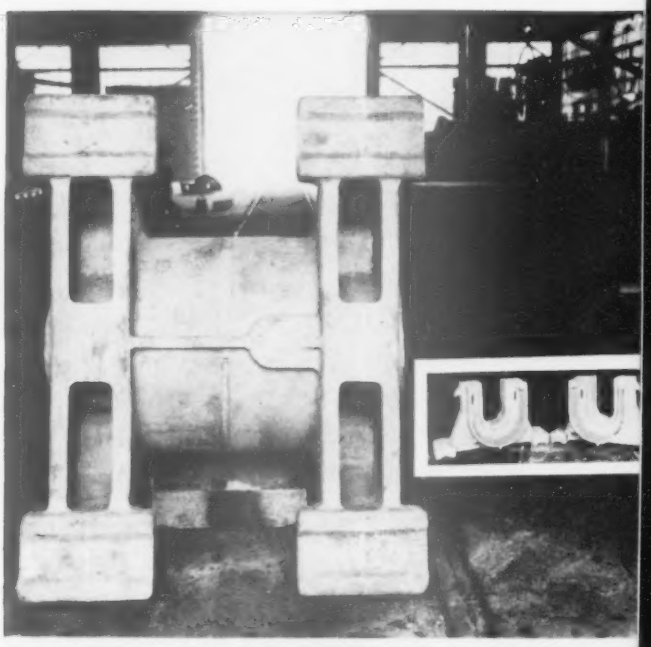


Fig. 12 Cast-weld rolling mill pinion housing

Fig. 13 Cast-weld hydraulic turbine stay ring

etc.). Cost reductions are possible to the purchaser because of savings realized by the foundry. These result from (1) reduced coring, (2) smaller flasks, (3) less sand handled, (4) reduction of labor in foundry and cleaning, (5) higher production rate, (6) improved service. It is well known that difficult-to-produce castings frequently require absorption of losses by the foundry; these become appreciable, considering that labor represents nearly 50% of all operating costs for a foundry.

The simplest application of cast-weld design is the elimination of protuberances or appendages, casting them separately and welding in place later. Salient features of cast-weld design will be apparent from the following examples.

Symmetrical sectioning as shown in Fig. 12 is typical of the adaptation of cast-weld structures. This rolling mill pinion housing is developed from two sections produced from a half pattern. A conventional casting would have required a large main body core and a full pattern. Note that the weld appears on the neutral axis, with ready accessibility to completely weld the double-vee butt joint without expensive fixtures. The double-bevels are cast and prepared for welding by superficial grinding.

Cast-weld design has transformed the hydraulic turbine stay ring section in Fig. 13 into readily castable components, consisting of top and bottom half crowns and separate vanes. A full casting of this size and design requires extreme care during molding and core setting to assure a satisfactory casting. Two-part cast-weld design, with weld joints at mid-section of the vanes, would reduce the amount of welding; however, dimensional control and alignment would be difficult to maintain by the foundry because of the tendency of the vanes to twist or warp. Separately cast vanes permit a great amount of flexibility, with the chance of dimensional inaccuracy being considerably diminished. As shown, the bevels are cast on the stubs and vanes and receive only light grinding in preparation for weld-

Fig. 14 Cast-weld ship stern frame

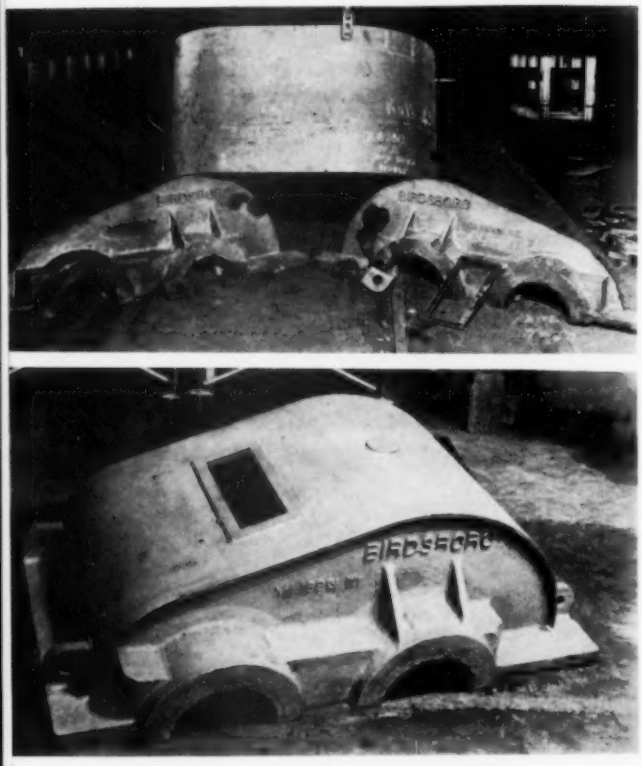


Fig. 15 Gear case cover composite weldment

ing. Note that the design permits single-welded joints—cored holes in the ends of the vanes and stubs materially reducing the weld-metal requirement. Casting these stubs to the crown section facilitates setup for welding, minimizing the problem of conforming vane ends to apron radius, and removes the weld from the immediate highly-stressed zone of the fillet. This welding is performed both by manual shielded-metal-arc process and semiautomatic submerged-arc process. Positioning in so far as possible on stay ring sections is for flat position welding. Welding sequences are followed which minimize stress build-up and the completed unit receives thermal stress relief.

A full casting of the design depicted in Fig. 14 would be notable for its dimensional instability. This ship stern frame would undoubtedly have required extensive heating and pressing to comply with drawing requirements. With cast-weld design, the natural components were cast separately. The sections were aligned and clamped to a strong back. Welding proceeded in the double-vee butt joints and no distortion was encountered.

The strut castings of Fig. 6 were treated as cast-weld and no unusual foundry problem exists with this type of casting. For larger-size struts, it has been possible to cast barrels, arms and palms separately. Welds in either case are full penetration, of considerable cross section and subject to radiographic acceptance.

Composite Structure Weldments

There is a wide range of products in which simplified casting design has given way to all-fabricated structures. Between all-cast construction and all-fabricated construction is a tremendous void into which castings and wrought materials can be combined in welded structures. This composite-type fabrication will frequently result in lower cost than either of these. The vast potential for composite structures ranges from incorporation of large quantities of plate and structural products with castings as a minor constituent to the instance where castings are a major portion of the design of these parts. These cast and wrought products are fusion welded by the methods described earlier.

One of the simplest examples of composite-type weldments is shown in Fig. 15. In designing these gear

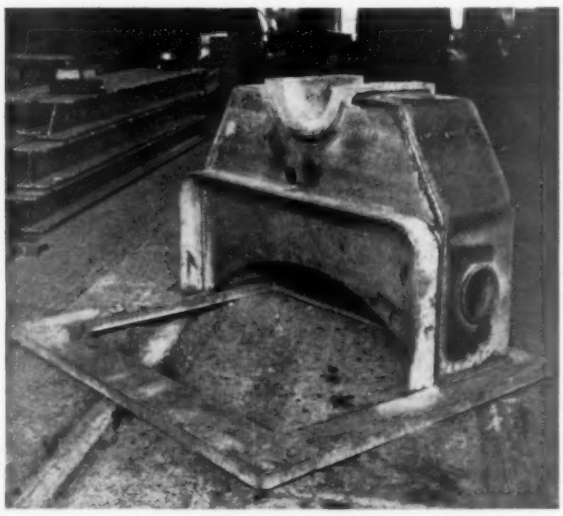


Fig. 16 Drive housing composite weldment

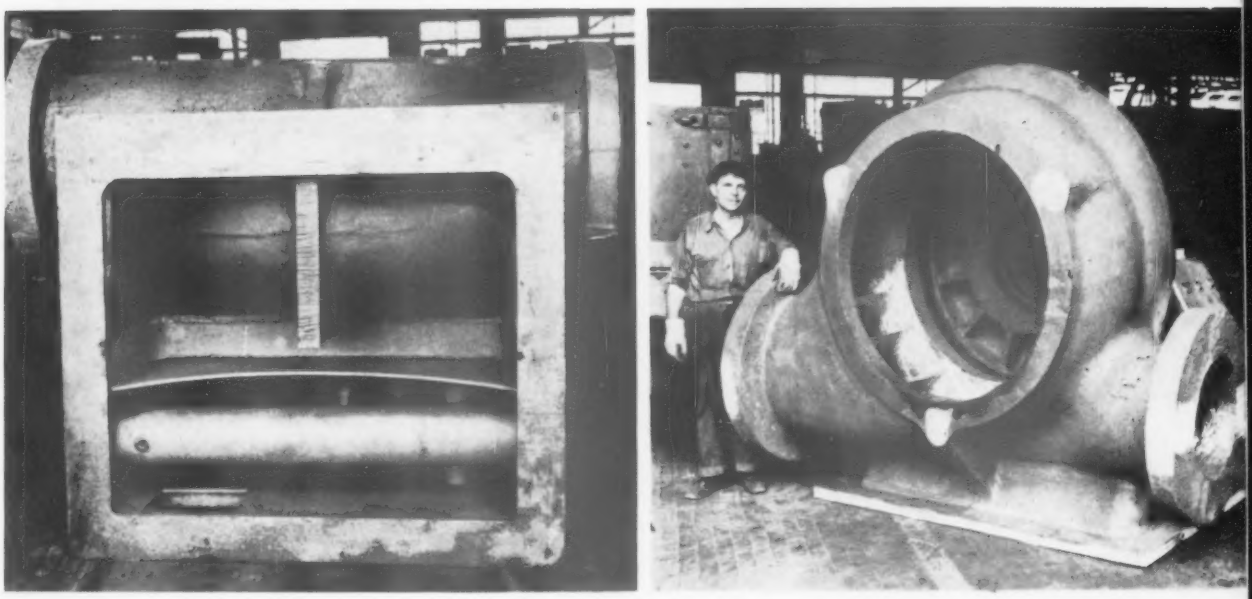


Fig. 17 Pump casing, base and drive housing composite weldment. Cast-weld pump casing

case covers, it is readily apparent that the castings have again been relegated to a position of easily-cast components. Joining the two side castings and minor appendages to the rolled plate is accomplished by fillet welds using the manual shielded-metal-arc process.

Figure 16 might very well have been included to show the extreme of composite weldments in which the casting, a bearing saddle in this case, comprises a minor portion of the structure. Full purpose of this rather complicated weldment is shown in Fig. 17. As a base and drive housing for a large pump case, this weldment has vastly simplified the casting design. Of added interest is the fact that there are three vanes welded into the casting which marks this as another cast-weld application.

A final example of composite-type structure is the ladder head for a suction dredge as shown in Fig. 18. Note that the shaft support is moderately-thin plate-steel fabrication joined to the casting. This would have been a very complicated casting.

Design Considerations

Now that cast-weld and composite welded structures have been illustrated, the approach to their engineering design will be considered. First and foremost, of course, is that a design is developed assuring the product performs its function in the service intended and is manufactured at the lowest possible cost. Whether new design or modification of an existing design, this can be assured only by collaboration of designer, welding engineer and supplier. Design engineers are responsible for determining the requirements of the product in withstanding static, dynamic and impact conditions of loading and special requirements such as corrosive environment, elevated temperature, low temperature, etc. Foundry technicians can assist in the adaptation of castings to the design and in the proper selection of material because of the wide selection of cast-steel analyses available for all service

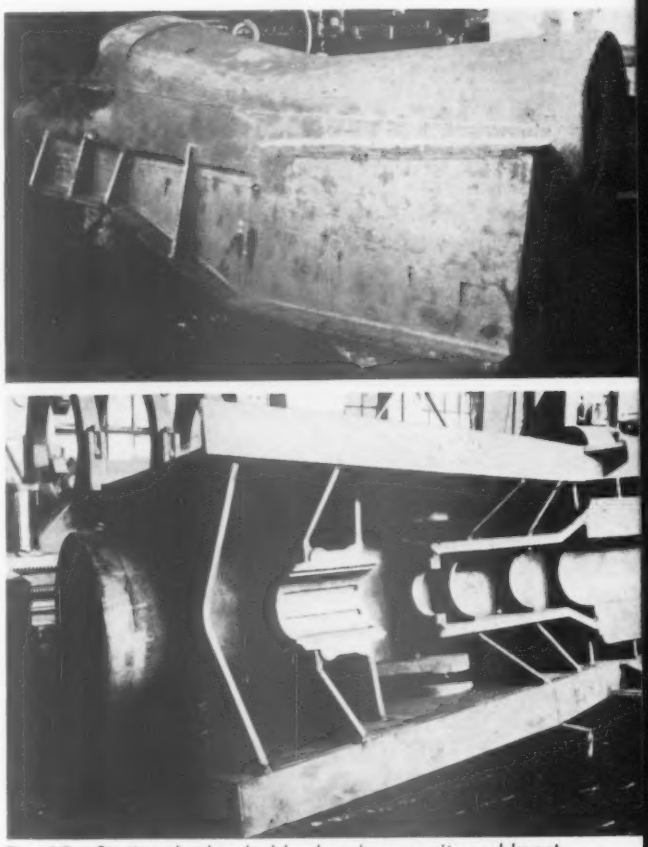


Fig. 18 Suction dredge ladder head composite weldment

requirements. He is also in a position to recommend simplification of design for improved casting quality. The welding engineer is necessary for determining the location of welds in relation to the sections joined, for the selection of the joint design commensurate with manufacturing practices and economy, and to detail the welding procedure.

Fundamental considerations to be kept in mind by all parties to these designs include the following:

(1) Design casting components utilizing the most favorable conditions to assure best quality. Essentially, this means keeping area to volume ratio low, simplifying patterns and eliminating the use of large, complicated cores. Thus, reduce complex forms to simple castings that can be welded.

(2) Select material specifications and weld metal specifications suitable for the service requirements.

(3) Follow the steps advocated for good weldment design; change sections gradually, avoid re-entrant corners. Avoid eccentricity. Eliminate high-restraint in localized areas. Avoid over-specification as much as oversimplification.

(4) Do not specify excessive welding.

(5) Use procedures for preparation, fitting and joining that will produce weld joints suitable for the service intended.

(6) Inspect adequacy of the welded joints.

A note of suggestion is that the joining of components by cast-weld, composite or all fabrication techniques requires very close attention to all costs, including material costs, pattern costs, number of units, erection layout, jigs and fixtures, machining, direct and indirect labor. All facts considered, the instances cited herein are typical of welded structures incorporating castings found to be cheaper than their single-casting counterparts.

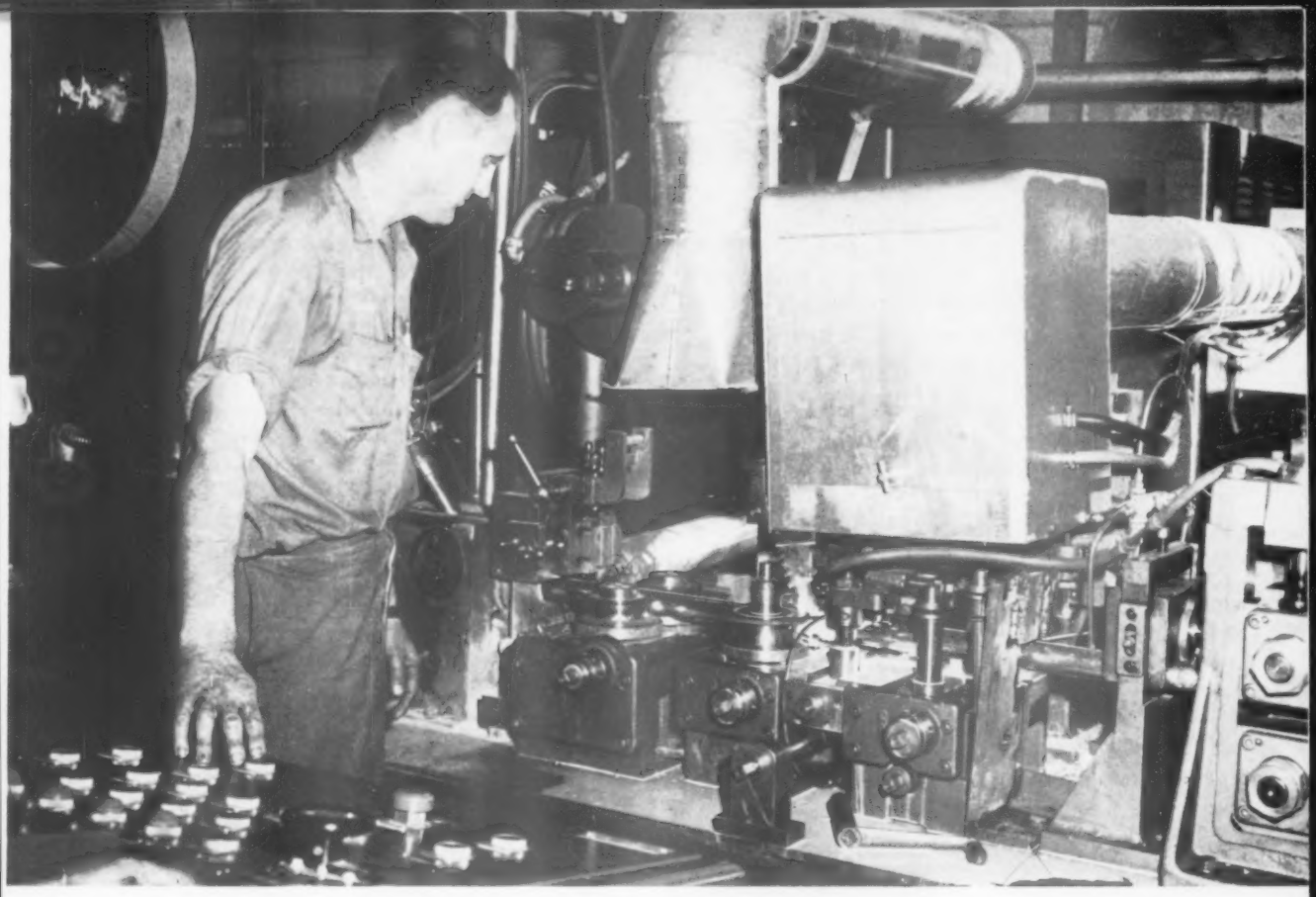
Future Requirements

Transcending the inherent contention between founder and fabricator, the welding industry as a whole has obviously profited from the increased utilization of their products and services in the modern foundry. To this end, with founders and welders so closely related, it is imperative that future technological improvements in welding equipment, electrodes, procedures, etc. should include a full-measure of thought to steel castings. Foundries are currently meeting increasing demands for higher-strength cast materials—supplying steel castings suitable for special applications involving heat, low-temperature, shock, wear and corrosion resistance. To weld these materials, many suitable electrode materials are available, but the future must bring such things as deposited-filler-metal chemistry within base-metal specification limits and heat-treatable filler metals. The latter should respond particularly to quench and temper heat treatments.

We have now demonstrated that the available equipment for welding and related processes in a modern foundry can compare favorably with that of a well-equipped weld shop. In addition, large size heat-treating furnaces, handling facilities, pressure blast cleaning equipment, and straightening presses are accessible. Supplementing the experience and know-how of casting production with the improvement in product design and casting quality through welding and its related procedures has indeed paid dividends to both the foundry and welding industries.

Acknowledgments

The author is deeply indebted to many individuals throughout the Birdsboro Steel Foundry and Machine Co.'s organization for their suggestions and help. The author wishes to express his appreciation for their cooperation and particularly to Mr. B. A. Kline without whose encouragement this paper would not have been possible.



Typical application of high-frequency resistance welding of steel tubing

HIGH-FREQUENCY RESISTANCE WELDING

A special case of high-frequency resistance heating now being used for tube and strip welding is covered in detail by the author

BY WALLACE C. RUDD

Introduction

High-frequency resistance heating is not a new technique but rather one that was lying dormant and now has been revived, and found to possess new vigor. High-frequency power for induction heating on the other hand has had an uninterrupted development over the years and today is a standard tool in industry.

For many years it was known that the resistance of metal to a current passed through it causes a heating effect. What was apparently forgotten is the simple fact that high-frequency current can be brought directly into the object to be heated by contacts as well as by transformer action or induction.

The use of contact methods to bring high-frequency current into a piece of work results in several peculiar effects, all stemming from the fact that current flows in the low-inductance path but not necessarily in the low-resistance path. For example, if two contacts are placed on a piece of metal approximately 2 in. apart, and 60-cycle (low-frequency) voltage is applied, what happens? Current will flow between the contacts in a somewhat uniformly distributed fashion depending upon the resistivity of the workpiece.

If high-frequency voltage is applied to these same contacts, it is possible to have practically no flow between the contacts and yet have a very high percentage of the current flow a distance of 40 to 50 in. over a path at a considerable distance from the contacts. This unexpected effect is achieved by simply making the path, through which the current flows, the low-induct-

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Presented at the Third Annual Midwest Welding Conference, Jan. 30-31, 1957, Chicago, Ill.

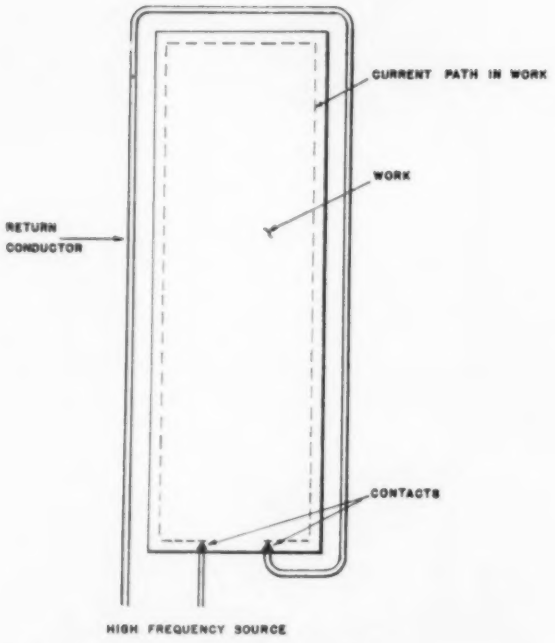

Fig. 1 High-frequency resistance heating

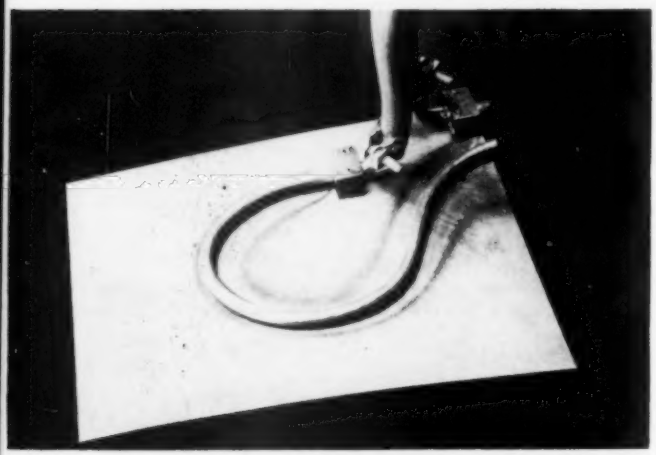

Fig. 2 Heat pattern follows (high-frequency) return conductor

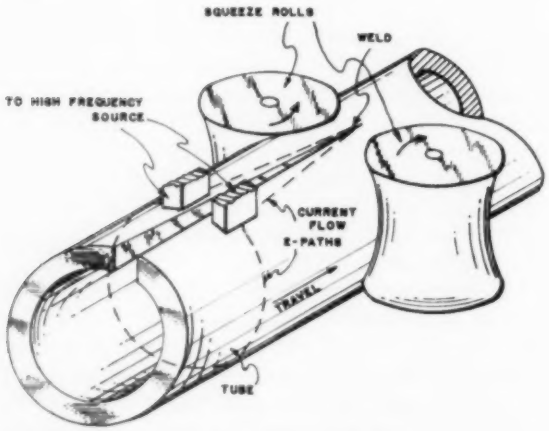

Fig. 3 High-frequency resistance welding

ance path. *The low-inductance path is normally the path which is closest to the return conductor of the circuit and this is the basis for all high-frequency resistance heating.* The current is permitted to flow through the work for a portion of the total circuit; the balance of the circuit is composed of a return conductor which follows closely (but is not in contact with) the path through which the current is desired to flow.

Figure 1 illustrates this basic principle, in heating a bar of steel around the outer three edges. Contact is made at two points on one end and the return conductor goes around the outer periphery back to the source. The current in the work flows in the dotted path, not between the contacts.

Another simple version of this phenomenon is shown in Fig. 2. Here two contacts are placed in a sheet of metal with the return conductor from one contact extending over a much longer path than the distance between the contacts. The actual path by the current is shown by the heated zone.

In creating a path of low inductance we are utilizing the natural tendency of the current to flow as close as possible to the return conductor. In this phenomenon, which we might call narcissism (self love), the current "loves" to get next to itself and to "hug itself," so to speak. This electrical phenomenon has many uses which we are applying to industrial processes; for example, the hardening of chain saw guide bar edges, hardening of shear blades and the annealing of wire.

Tube and Strip Welding

This paper deals with a special case of high-frequency resistance heating now being used for tube and strip welding.

In conventional tube welding, two roll-type electrodes are brought into contact with the unwelded seam of the tube. Current flows from one electrode to the other across the seam, which is heated by resistance, a large portion of this resistance being the contact resistance of the two edges as they are brought together.

High-frequency resistance welding is fundamentally a matter of bringing high-frequency current into the tube and causing only the edges to be heated, then pressing the two edges together to form a forged-type weld.

In operation (see Fig. 3) the tube is formed in the usual way and pressed together from the open seam condition by a set of squeeze or weld-pressure rolls. Because the tube is pressed together from the open state, a small triangle is formed with the weld point as the apex and the two edges as the sides. This triangle may vary in size according to the diameter and wall thickness of the tube and the material being welded.

Now when high-frequency power is introduced, by means of a pair of contacts just in advance of the pressure rolls, there will be two current paths (see Fig. 3). One path is from one contact around the back of the tube to the other contact; the second path is from one contact along the edges of the tube (being welded) then back along the opposite edge of the tube to the other contact.

These two paths may be considered to be connected in parallel; however it should be noted again that inductance determines the path of the high-frequency current. The *lowest* inductance path in this case is the one between the two side seams of the tube to be welded. The path around the back of the tube is one of *high* inductance, since inductance is proportional to the square of the tube diameter.

The result is that almost all the current flows along the two edges of the tube just preceding the weld point, and heats these two edges in the gap between the tips of the contacts and the weld point. The same current that flows in one edge of the tube flows on the opposite edge. In effect each side of the tube is the return conductor for the other side. Thus only the two surfaces to be welded are heated. This is a perfect case of high-frequency resistance heating.*

The current used in this type of high-frequency resistance welding is in the order of 450,000 cps. At this frequency, current flows to a depth of only a few thousandths of an inch (in magnetic materials) and therefore only the surface of the item is heated. Any heating effect under the surface is strictly thermal conduction. In the case of tube welding where the speeds are very high there is little time for thermal conduction. Metallurgically, the material affected is at a minimum and in some metals the weld cannot be detected, a highly desirable feature.

Direction of Current Flow Different in High Frequency

There is a fundamental difference between high-frequency resistance welding and conventional electric resistance welding. This difference is in the direction of current flow and yields many advantages for the high-frequency method.

In ordinary (low-frequency) resistance welding the current travels from one piece of metal to the other at *right angles to the weld axis*. This means that the heat produced in the weld is a function of: the current, the surface condition, metal resistivity, pressure of the two surfaces and the contact resistance. All these factors are variables and cause "fussiness" in the welding operation.

By contrast, in high-frequency resistance welding the current *flows parallel to the weld axis*, and flows along the surface of the two pieces being welded *before* they are in contact. Therefore surface condition, pressure or other contact resistance factors do not enter into the heating effect. The metal being moved toward the welding point is already at weld temperature, the pressure at the weld point squeezes out any molten material and bonds the metal together in the plastic range, producing the best type of forged weld.

In very small diameter tubes the inductance of the path around the back of the tube may be low enough so that some current flows in this area. This diverts current from the weld zone and causes unnecessary heating. To overcome this undesirable condition it is only necessary to increase the inductance around the tube. This is accomplished by a device called an impeder, which is a water-cooled magnetic core placed within the tube underneath the contacts. In some cases, magnetic material is used around the exterior of the tube. The impeder makes more current available for welding and permits greater welding speeds in small diameter tubing.

Contact Problem Overcome at High Frequency

In utilizing high-frequency resistance heating at 450,000 cps, it was found that the contact problem in bringing 1000–2000 amp into a piece of work was negligible as compared with the same arrangement at 60 cycles or even 10,000 cycles. The phenomena which overcame these contact problems are responsible for the commercial success high-frequency resistance welding is achieving.

Under usual conditions, the electrical engineer is skeptical about the practicality of bringing 1000 amp into a workpiece with a sliding contact having an area $\frac{1}{4} \times \frac{1}{16}$ in. Yet at 450,000 cycles this is an easy matter. The underlying reasons which account for this are:

1. At 450,000 cycles the effective resistance of the metal being heated is much higher than at 60 cycles. Now the heating effect is a function of the current squared multiplied by the resistance. Therefore, if the resistance is increased, the current can be decreased accordingly to achieve a given heating rate.

Therefore, to do a particular heating operation at 450,000 cycles requires only a fraction of the amperage used at 60 cycles. Because contact life and area are strictly a function of current handled, the less amperes used the more simplified the contact design.

2. One of the major negative factors about contacts is that they heat, the contact material softens, even melts and causes arcing. If contacts are properly cooled, much higher currents can be handled without undue problems. This has been recognized in the spot-welding industry where refrigerants are sometimes pumped through spot-welding contacts.

In high-frequency welding, the contacts are cooled by an internal stream of high velocity water, extracting the heat at the exact point it is being created.

3. All metals, even those freshly cut or cleaned, have some degree of oxide coating. This film may be infinitestimally thin or, like the scale on hot-rolled steel, several thousandths of an inch thick. These oxide coatings, with one or two exceptions are, for all practical purposes, nonconducting materials and with ordinary contacts present a problem. At 60 cycles this oxide must be crushed through and physical contact made with the basic metal underneath. This condition is recognized in the welding industry where 60-cycle power at 1 to 3 v and several thousand amperes must flow through the electrodes. The oxide coating acts as an insulator, prevents heating and a poor weld results.

At 450,000 cycles this oxide coating is no longer a barrier but a welcome asset. As an insulator it may now be considered as the dielectric of a capacitor where

* The process is covered by patents and patents pending.

the two plates are (1) the sliding electrode and (2) the metal under the oxide coating. Thus with higher frequency (above 100 kc) and sliding contacts, the current is carried into the metal being welded by *capacitive action* and no crushing of the oxide coating is required.

In welding, for example, hot-rolled steel which has not been pickled or sandblasted, the contacts slide on top of the scale and carry 1000 (or more) amp into the workpiece with no arcing or sparking.

Because there is no need to crush the oxide coating, high-frequency resistance welding is accomplished with comparatively slight pressures, allowing thin material to be handled without collapse.

High-Frequency Resistance Strip Welding

So far we have been referring to high-frequency resistance welding as it is applied to tube welding. The basic principle is the same for strip welding. Figure 7 is a photograph of a strip mill used for continuous welding of zirconium strips 1 in. wide by 0.155 in. thick at speeds above 100 fpm. An atmosphere of argon is used at the contact and weld zone to prevent oxidation of this pyrophoric material.

Another unusual use of the strip-welding process is welding together two different grades of steel. For example, welding high-speed steel to high-carbon steel for industrial hacksaws and band saws. The teeth are cut in the high-speed steel while the lower-cost carbon steel acts as backing.

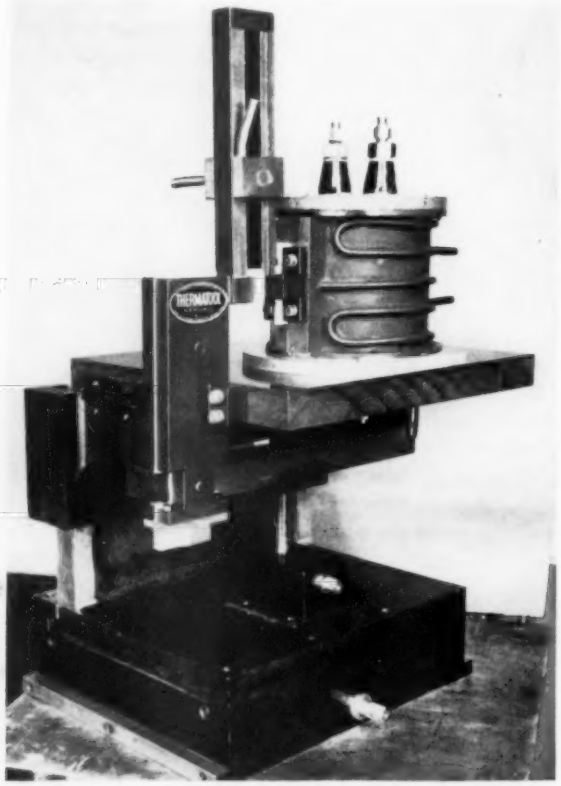

Fig. 4 High-frequency welding head-transformer leads and contacts

Description of Welding Head

A typical welding head used for high-frequency tube or strip welding is shown in Fig. 4. The cylindrical device on top is a high-frequency transformer with an input of approximately 3000 kva and 50 kw. The secondary of this transformer feeds (at about 100 v) a pair of water-cooled copper leads which carry the welding current down to the contacts on the bottom of the leads. The contacts, in turn, rest on the top of the tube just ahead of the weld-pressure rolls. These contacts are water-cooled, water entering through "O" ring gaskets from the leads above. Each contact block is held with two screws so that replacing the contact and repairing is a simple procedure.

The service life of the contacts varies with the kind of metal being welded. With aluminum, the contact life extends up to two weeks, equivalent to several hundred thousand feet of material. On cold-rolled steel, at least 8 hr of operation can be done before redressing. Contact life is reduced, understandably, on hot-rolled steel where the scale is highly abrasive.

The weld head is normally mounted on an adjustable device which allows the contacts to be brought down on the tube just ahead of the squeeze rolls (see Fig. 5). In some cases where the tube is imperfectly formed, it is advantageous to have movable contacts so they can follow the uneven contour in the metal as it enters the weld-pressure rolls. Figure 6 is a general view of the welding section of an aluminum (irrigation) tube mill.

Adjustment of Power Level

To adjust the power level of the 300-kva welding head, two very simple devices are used. In one case, where the forming mill speed is variable, a bar-type reactor is installed in series with one lead of the weld head. Adjustment of the "shorting" bar (Fig. 4) changes the current flowing in the weld. The bar is set, before operation begins, for the approximate power level desired, the mill speed is then adjusted to produce the required weld.

A second arrangement (Fig. 7) permits the power level to be adjusted with "power on." This power output control consists of a smaller type series reactor without the short-circuiting unit. A copper block with an opening is placed in series with one lead of the weld head as a series inductance. The inductance of this copper block is varied by sliding, in or out, a reactive changing device. This type of "push-pull" output control can be operated by a servomechanism through information relayed from an optical temperature instrument, continuously examining the weld temperature as the metal passes the contacts.

The power source for this welding is a special high-frequency vacuum-tube oscillator with a usual output of either 25 or 50 kw at 450 kc. If higher mill speeds of greater wall thickness is specified, larger generators can be used.

In high-speed welding of some materials it is essential

that the ripple in the envelope of the output radio-frequency current be less than that of a conventional power supply. This is accomplished by choke and capacitor devices in the generator, reducing the 5% normal ripple to a negligible value. This eliminates the "stitching" effect at the weld.

Advantages of High-Frequency Resistance Welding

High-frequency resistance welding has a number of important advantages over conventional methods. Speeds are extraordinary by comparison; for example, aluminum tubing is production welded at 250 fpm and steel tube of $^3/_8$ in. diam has been welded at speeds over 400 fpm.

In conventional resistance welding, the contact resistance is of prime concern. The proper condition of the edge of the workpiece becomes a problem. With high-frequency resistance welding, edge condition is relatively unimportant; it is only necessary to avoid excess oxide on the internal edge, so that no inclusions develop in the weld.

Sometimes segregation takes place in steel ingots and is transferred to the coils. Where this occurs, welding by conventional means is extremely difficult. This condition has no noticeable effect with high-frequency resistance welding.

The heat-affected zone is much less, because high-frequency power densities and welding speeds are much higher. This results in a superior metallurgical structure and tends to give a much more ductile, thorough weld. There is no tendency to form internal spatter or to create a large internal bead. Frequently the internal bead can be made negligible and, without inside spatter, cleaning of the tube is not required.

Maximum utilization of welding power is achieved since power only heats the weld zone. There is negligible heating around the back of the tube.

There is every reason to believe that any material that is weldable can be welded by the high-frequency process, either as tubing or strip. The metals that have been successfully welded to date include: Aluminum, steel (mild, high-carbon, high-speed, stainless), copper, brass, silicon bronze, Monel, Inconel, Incaloy and zirconium.

In some types of aluminum tube, this process is competitive with extrusion; but it should be noted that aluminum-alloy tubing of high tensile strength is easily welded with high-frequency power but is not produced by the extrusion process.

Copper tube and pipe of *100% electrical conductivity* is being continuously welded at high rates of speed. The quality of this product meets or exceeds the specifications for the best refrigeration grade of pierced and drawn tube.

Another interesting development in copper welding is a new type cable being considered for the next transatlantic telephone cable. High frequency makes it possible to weld a copper tube surrounding a steel core without heating the steel, a feat never before accomplished.

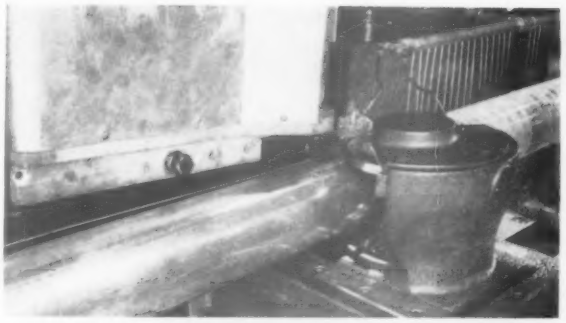

Fig. 5 Aluminum tubing (irrigation) being welded. Note contacts near squeeze roll

Fig. 6 Over-all view of welding section of tube mill (as in Fig. 5)

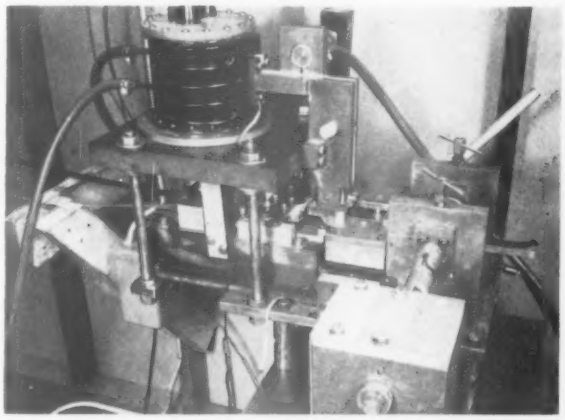

Fig. 7 Continuous strip welding showing two different steels welded together at discharge side of mill

Versatility and Potential

The versatility of a high-frequency tube mill is demonstrated by its ability to produce different metal tubes in a wide variety of sizes with the same weld head. If one wished, steel, aluminum and copper could be run in the course of a regular shift.

High-frequency resistance welding, by permitting higher power densities, greater speeds and superb versatility, is a recent development. Yet, in a comparatively short time, it has attracted world-wide attention not only for its commercial possibilities but for applications in the field of nuclear power plants and supersonic airframe construction.

Practical Welder and Designer

AUTOMATIC OXYGEN CUTTING SPEEDS PARTS FABRICATION

BY J. O. McELLIGOTT AND N. C. BRINK

At the Henry Manufacturing Co., Inc., Topeka, Kan., automatic oxygen-cutting equipment is demonstrating its ability to fabricate parts for earth-moving machinery, backhoes, tractor-shovels and backfill blades faster, better and cheaper than before (Fig. 1).

Increased production, speed and economy mean savings for the company, while durable construction pays off in longer life and lower maintenance for users of their earth-moving equipment.

The transverse carriage-type machine (Fig. 3)oxygen cuts, automatically, over 350 separate parts out of steel sheets. Guided by an electronic tracer, four torches simultaneously produce intricate shapes. This oxygen cutter not only reduces jig-setting time but also makes maximum use of steel plate.

For example, 156 parts for Henry equipment can be cut from a $^3/_8$-x 72-x 120-in. sheet of steel plate, weighing 918 lb (Fig. 2). The economy of the operation is shown by the fact that only 15 lb of scrap remain after one of these cuttings.

More and more manufacturers are discovering the advantages to be gained by using oxygen-cutting machines for speedy, economical parts to produce many types of equipment.

J. O. McElligott and N. C. Brink are associated with Air Reduction Sales Co., Kansas City District, Kansas City, Mo.

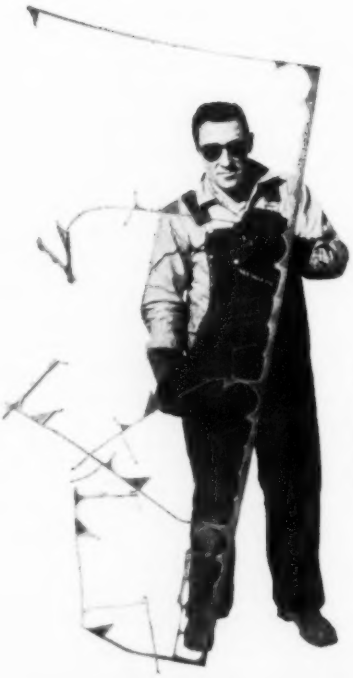

Fig. 2 918 lb of $^3/_8$-in. sheet steel, less 156 oxygen-cut parts—leaves only 15 lb of scrap

Fig. 1 Henry hydraulic backhoe with telescopic boom and hydraulic tractor shovel, mounted on a standard tractor, digging a water line for an air base project

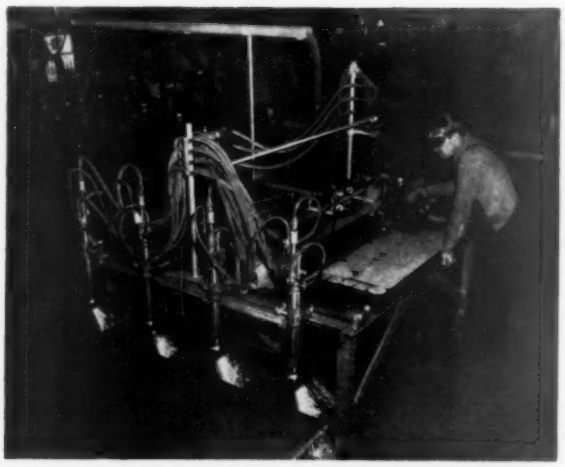

Fig. 3 Transverse carriage-type machine automatically oxygen cutting varied shapes from single sheet of metal

INERT-GAS METAL-ARC WELDING PREVENTS B-52 PRODUCTION DELAY

When a large crack developed in a 9000-lb aluminum platen—needed to produce parts for the giant B-52 airplane—inert-gas metal-arc welding was rushed to the rescue. In just $9^1/_2$ hr, the crack was welded and the platen returned to service.

As a result, Fairchild Aircraft Division of Fairchild Engine and Airplane Corp., Hagerstown, Md., was able to salvage a critical platen used in manufacturing assemblies for the B-52—a bulwark of our country's defense. Welding avoided a six-week delay for a new platen to be cast and machined.

The aluminum platen is approximately $^1/_2$ ft thick, 5 ft wide, and 17 ft long. As cast, it contains vacuum and pressure piping, heating units and a water-cooling system. Successful welding was especially important since these intricate components were exposed by the 2-in. deep crack, which extended about 23 in. on each side of the platen.

The welding operation was performed at a current setting of 200 amp DCRP, with aluminum rod $^1/_{16}$ in. diam. Inert argon gas was employed to prevent atmospheric contamination of the weld area.

After the crack was chipped to provide a groove for welding, the platen was preheated to 325° F. All welding was done in a vertical position—thus speeding repair, since alternate welds could be made on each side of the platen. To minimize stress buildup and undue porosity, each pass was peened before the next pass was made.

With the platen returned to service, the inert-gas metal-arc welds successfully withstood stresses of 350° F heat and subsequent water quenching by the units inside the platen.

Based on a story by the Linde Co., New York, N. Y.

Fig. 2 Here is a top view of the weld made with inert-gas metal-arc welding in only $9^1/_2$ hr

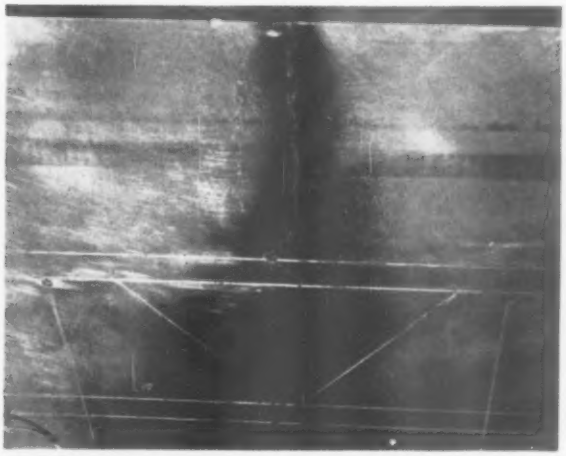

Fig. 1 The 2-in. deep crack extended about 23 in. on each side of the aluminum platen

Fig. 3 With the crack repaired, the platen is ready to produce vital parts for the giant B-52

MULTIPASS WELDING OF STEEL PIPE WITH CO_2

BY E. A. QUINLAN, DON ALRICK AND A. P. DEMMER

Automatic multipass welding of large diameter steel pipe with CO_2 as the shielding gas is another new technical success for the gas-shielded metal-arc process.

Twenty-five miles of 12 3/8-in. diam pipe with 3/8-in. thick wall—for waste tailings from the Taconite Co.'s dump area in Aurora, Minn.—shaped up as a major project with one big question: what was the best way to join the 40-ft lengths of pipe into 200-ft sections (each 200-ft section also required the welding of flanges at each end for field connections).

Demonstrations of four welding processes were witnessed by Peter Kiewit Sons' Co., contractors on the job, but the answer came quickly when the gas-shielded metal-arc process was demonstrated with the automatic welding head, using CO_2 as the shielding gas (see Fig. 1).

Three passes were made on a butt joint with 30-deg bevel around the circumference. A guide roller was used for aligning the pipe and turning the 40-ft sections under the welding head and positioner. The positioner was incorporated with the welding head for fast positioning and for elevating the head as pipe is pulled through the welding station. Welding time was 1 min per pass or 3 min per weld on both butt welds and flanges.

The welding operation involved the use of A-675, 1/16-in. diam wire with 20 cu ft of CO_2 per weld. Eighty-five percent penetration was obtained with 10% reinforcement, the surface showing minimum of spatter and a uniform bead without undercutting. Strength of the weld was equal to E6012 electrode strength.

E. A. Quinlan, Don Alrick and A. P. Demmer are associated with the Air Reduction Sales Co., Minneapolis District.

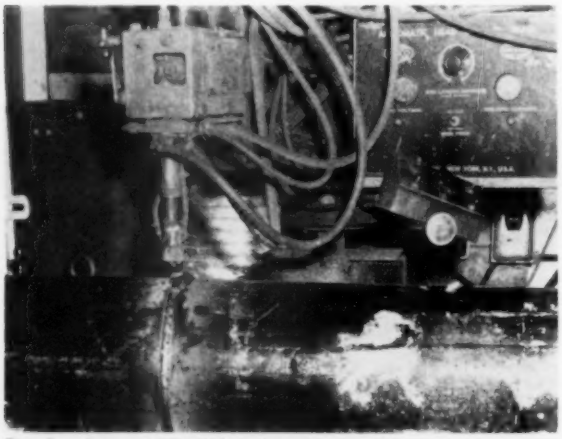

Fig. 1 Automatic welding head in position

Circumferential weld is made in three revolutions. The head is stationary. Pipe is turned under head.

Fig. 2 Pipe (40 ft) welded in 200-ft sections, with flanges on both ends for field connections

An enclosed welding station or "house" provided protection for the equipment and operator for welding operations at temperatures below zero—normal weather conditions encountered in the "iron range" area during Minnesota's long winters (see Fig. 2).

Figure 3 shows 200-ft long sections loaded on truck dollies.

Fig. 3 A 200-ft long section pipe loaded on truck dollies, spaced 40 ft apart, using a truck with a boom arrangement to snake the pipe into position for coupling to flanges

NEW BUILDING HAS MILES OF WELDING IN UNIQUE EXTERNAL COLUMNS

BY RUSSELL S. HALE

The new Inland Steel Co.'s 19-story building in Chicago has no internal columns. Each floor, before partitioning, has an unobstructed area of 57 x 175 ft supported by 60-ft girders which are attached to external columns. Fabricated from structural steel and steel plate up to 3 in. thick, the columns were welded with both the semi- and fully-automatic submerged-arc welding processes. Approximately 30,000 ft of welds are involved—over five miles!

The columns vary in size from bottom to top. They were shop fabricated in 26-ft lengths, for the most part, with some of the heavy bottom sections weighing up to 18$^1/_2$ tons each. Flange thicknesses varied from 1 to 3 in., and webs were from $^5/_8$ to 1$^1/_2$ in. thick. Note the end section under the welding head in Fig. 1. When erected the lower portion of the column is the outside and is encased in concrete, while the top of the column as seen in the picture is the inside or girder side. Note also the number of large fillet welds required on the column. The number of welds and the 26-ft normal length of each made it necessary to set up on a production basis to economically make the total 150 sections required for the building.

The bulk of the welding was done with a twin-arc automatic welding head mounted on a universal ram-type, carriage mounted fixture. The twin-arc welder is a submerged-arc unit which uses two $^1/_8$-in. electrodes operating into one arc and is well suited to this job because it has a deposition rate considerably above that which can be obtained with a single wire. The supply of welding current is two 750-amp motor-generators connected in parallel and mounted on the fixture carriage.

The fixture runs on a 65-ft track at welding speeds and at fast travel speeds for alignment and other movements. The boom can be rotated on the carriage to allow welding on either side of the track.

In setting up for welding, the long track of the fixture was used to good advantage by setting up four separate column sections, two on each side of the track. This provided maximum use of the welder with little or no time lost while pieces were moved or replaced. The 26-ft sections were placed in cradles and positioned.

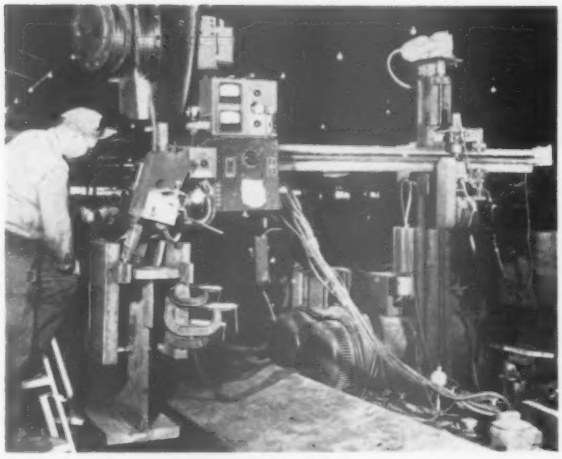

Fig. 1 Arrangement of fully automatic submerged-arc welding machine for welding large column section

The head is adjustable on the end of the boom for final alignment.

Normally, both edges of the heavy plates were beveled to use the minimum amount of weld metal. Where the back side of the weld was inaccessible a single bevel was used. A $^5/_8$-in. flat barstock was used for backing behind the beveled edge to eliminate burn-through. Runout tabs were used on the ends of the columns. An acetylene torch ahead of the arc was used when plates were unusually cold or damp. Welding speeds on the heavier plate were about 7–9 ipm and increased to 30 ipm on the lighter plate. Unfused

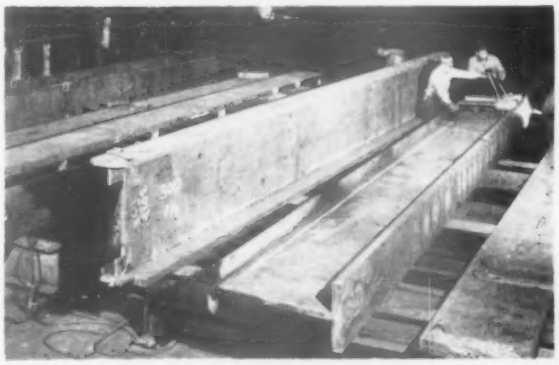

Fig. 2 Straightening large column section after welding

Russell S. Hale is District Engineer, The Lincoln Electric Co., Cleveland, Ohio.

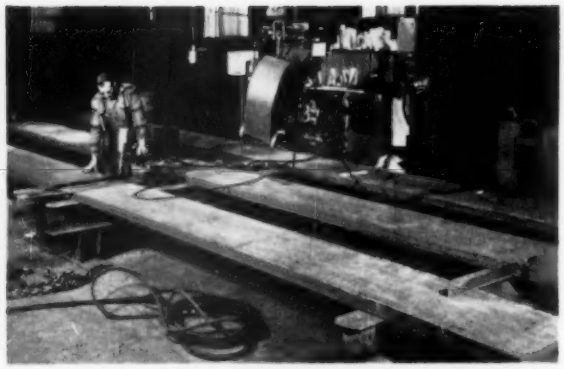

Fig. 3 Semiautomatic submerged-arc welding machine mounted on cutting buggy splices slabs for 42-ft column sections

flux was picked up about 5 in. behind the arc with a vacuum unit mounted on the fixture. The columns were allowed to cool between welds.

Allowing the columns to cool between welds, welding as fast as possible, and clamping identical parts back-to-back were methods used to minimize warpage. Final straightening before machining the ends was accomplished with a heating torch and hydraulic jacks. Figure 2 illustrates this operation.

A semiautomatic unit was used on some of the lighter sections and to splice plate on some 42-ft sections where slabs were unavailable in the required length (Fig. 3).

LARGE STEAM VALVE WELDED WITHOUT PREHEAT

BY H. B. BOTT

The welding department of The Consolidated Edison Co., like that of many other companies, is constantly called upon to assemble and repair equipment under conditions somewhat less than ideal.

Many repair jobs must be done overnight; relatively complicated overhaul and maintenance work must often be done over a weekend. In addition, both types of jobs frequently must be done in the field where facilities are limited and working conditions difficult. However, in all instances, it is of prime importance that the machinery be put back in service as soon as possible. A broken steam line, valve or a con-

H. B. Bott is associated with Mechanical Engineering Section, the International Nickel Co., Inc., New York, N. Y.

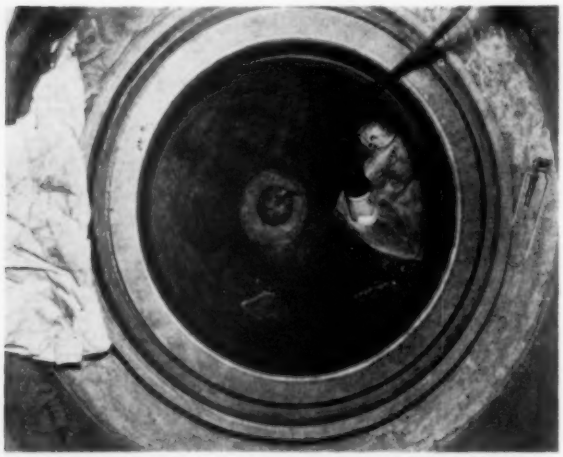

Fig. 1 Welder's view of the problem. It would be impossible to work inside this valve if it were necessary to preheat before welding

Fig. 2 Typical local crack that needed repair. Some cracks were 10 in. long and 3 in. deep

Fig. 3 Interior view of valve body—after welding—but not before cleaning. Note close quarters for welder

Fig. 4 Interior view of valve after cleaning

denser failure can cause a complete generating system to be shut down.

Because this need for time saving is coupled with that of maximum reliability, welding departments of these companies must continually seek and adapt new techniques and equipment to their needs. Thus they found most helpful a new type of electrode having about 70% nickel, 15% chromium and 10% iron as its major constituent. One of the principal advantages of this electrode is that it substantially reduces the need for preheating and postheating of many engineering alloys.

Preheating can be a major obstacle in maintenance and repair work. For example, equipment of sufficient capacity to heat a large valve or turbine housing to 500 to 600° F is not generally available, and the time required to do the heating may keep the unit inoperative for several days although the actual welding may only take a few hours. Furthermore, some units cannot be heated to these temperatures because adjacent or integral members would distort, or because it might be necessary for the welder to work inside the part while making the repair.

A typical example of how the use of the new nickel-chromium-iron electrode has simplified repair operations at Con-Edison is represented by the large throttle valve shown in Figs. 1 through 4. This housing, which is made from carbon-moly steel, was removed from service because of a dozen or more cracks in the lower section. As shown in Figs. 1 and 2, some of these cracks were 10 in. long and 3 in. deep.

With the new electrodes, the entire job was completed in a few hours without any preheating or stress relieving. Three men worked simultaneously inside the valve, the entire operation resembling an assembly line. Welds were made in almost every position, using cut-down electrodes because of the close quarters. Figure 3 shows some welds before cleaning; Fig. 4 shows the finished job.

All welds were carefully inspected and approved without delay; however, the fact that the valve has now been back in service for several months is perhaps the best indication of weld quality. Had it been impossible to complete the repair successfully, the company might have been faced with waiting more than a year to get delivery on a new unit.

BOUND VOLUMES OF 1956 JOURNAL NOW AVAILABLE

Bound Volumes of THE WELDING JOURNAL for the year 1956 are available in black imitation leather covers, together with a comprehensive subject and authors index. Price $15, including postage.

This volume, comprising a total of 1296 pages in the JOURNAL and an additional 624 pages in the *Welding Research Supplement*, represents a veritable encyclopedia of information in the welding field. Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

SURFACING MEANS SAVING

By hard surfacing worn cylindrical parts with submerged-arc welding, Great Lakes Welding Co. of Detroit, Mich., saves its customers the burdensome expense of new equipment. The submerged-arc-welding process is proving its hard-surfacing value by combining high speed and quality with low cost and labor requirements.

Using a submerged-arc welding head, installed on each of two lathes, this company quickly surfaces such parts as paper mill rolls and blooming mill table rolls. These parts would have to be scrapped unless rebuilt by hard surfacing.

One lathe handles parts up to 54 in. diam and 18 ft long, while the other takes pieces up to 30 in. diam and 12 ft long. The lathes are adjustable, permitting surfacing of different diameters on a single part.

Supported on the lathe tool carriage, the welding head moves automatically at a set rate, while the worn part is rotated by chucks which are driven by the headstock. The rotating workpiece is grounded by a sliding contact which bears against the outside of the chuck. The flux hopper, containing No. 80 flux, and the wire reel are positioned above the head.

Since the controlled operation of the welding head is fully mechanized, parts are surfaced with a minimum of operator time. Once welding starts, the machine continues automatically — requiring only occasional attention. Welding speeds vary from 30 to 60 ipm. depending upon the thickness of the deposit.

Based on a story by the Linde Co., New York, N. Y.

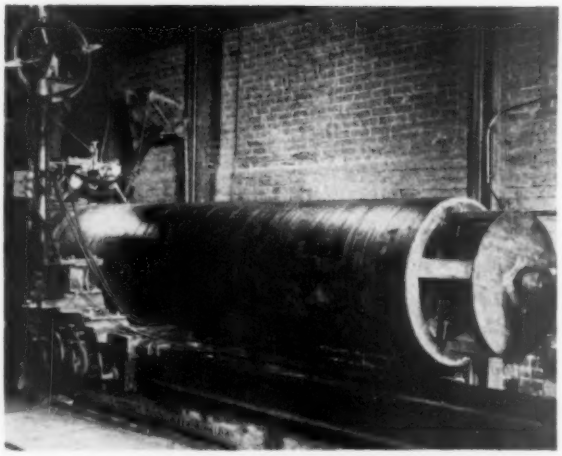

Fig. 2 One of six passes is being made to deposit a $^3/_8$-in. thickness of stainless steel on a paper mill roll, 3 ft in diameter and 13 ft long. After grinding, the hardness of the surface will equal that of a new roll

As the metal is deposited, each weld bead unites with the bead next to it as well as with the metal below. If required, several layers of metal are deposited until the original diameter of the part is restored. By using the proper wire, a surface is produced that is actually harder than the original part.

After the metal is deposited, the new surface is machined or ground to provide any desired finish. The hard-surfaced part is returned to service at a fraction of the new-part cost.

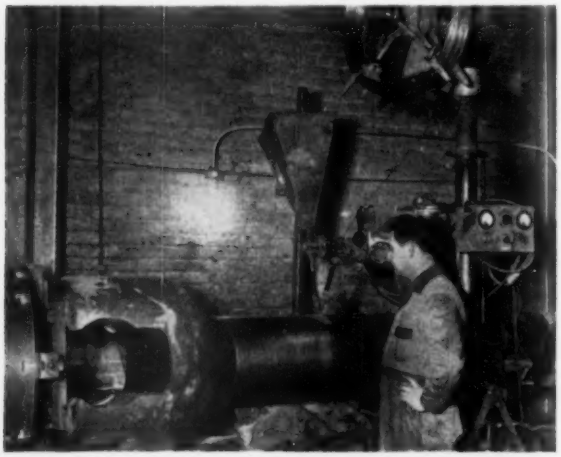

Fig. 1 This is the first of three passes needed to restore a 20-in. diam on a spindle for a blooming mill drive. The submerged-arc welding head, flux hopper, wire reel and welding controls are moved by the lathe tool carriage

Fig. 3 Here are two paper mill rolls after surfacing. One of the two lathes used for submerged-arc hard surfacing is shown in the background

Society News

Magrath Leaves American Welding Society Post

Joseph G. Magrath recently notified the Board of Directors that, concurrently with the ending of his present term on May 31, 1957, he would resign his post as National Secretary of the AMERICAN WELDING SOCIETY. Mr. Magrath's resignation, which has been received with deep regret, brings to a close a very successful term of ten years as chief executive officer of AWS.

Mr. Magrath became best known to AWS through his activities with the Air Reduction Sales Co. Here, he supervised market, process and product demand surveys and sales promotion work through sales and service engineering staffs of 26 district offices. He collaborated with displays, conferences and technical society activities. He was concerned with sales-service instruction and promotion meetings, and gave numerous talks before industrial executives and engineering society groups.

During World War II, while still associated with Airco, Mr. Magrath was extremely active in the application of welding, cutting, brazing and other flame-treatment processing of welded fabrication in all of the larger shipyards on the East, Gulf and West coasts as well as in inland plants and steel mills connected with the war effort. Prior to assuming his position with AWS, he was sales manager of the McAlear Manufacturing Divisions at Tulsa, Oklahoma, and Chicago, Illinois, of Climax Industries, Inc., subsidiary of General Finance Corporation of Chicago, Illinois.

Mr. Magrath is a registered professional engineer in the state of Illinois and is a member of the American Society for Metals, the Society of American Military Engineers and the Steam Specialties Club, New York. He was also active in the New York Section of AWS and served for several years as its chairman of publicity and programs.

Joseph G. Magrath

Upon assuming the office of National Secretary of AWS in 1947, Mr. Magrath set a high goal for our SOCIETY to attain:

(*a*) An activity serving and aiding every person, manufacturer, user and association in welding;
(*b*) A membership of 30,000 individuals and 1500 companies by 1965.

Much progress to this end has been made in that between 1947 and 1957 the SOCIETY's membership increased 70% to 12,580, its Section number 50% to 82, and its activities threefold, including a new and most successful welding exposition.

"The Secretary," Mr. Magrath stated in his letter of resignation, "hereby registers his heartfelt appreciation to all National and Section officers, SOCIETY members, Staff officers and members, welding manufacturers, industrial users and organizations who have made possible the accomplishments of the past decade. During his past ten terms he has considered his appointments a distinct honor. His decision to withdraw his candidacy has been announced with genuine regret. He plans activity in other fields."

•

"Joe," as he is called by his host of friends all over the country, has devoted a great deal of time, strength and keen judgment to the responsibilities placed upon him. He has been tolerant in his effort to meet the various needs of our members and an inspiration to its succession of officers and committee personnel.

Joe's many friends in AWS wish him good luck and happiness in his new activity. The Board of Directors express their personal and collective thanks for a job well done.

American Welding Society Names Plummer Secretary

Fred L. Plummer

As announced in the June issue of THE WELDING JOURNAL, Fred L. Plummer has been appointed national secretary of the AMERICAN WELDING SOCIETY by the AWS Board of Directors. The appointment, which became effective on June 1, 1957, has been made to fill the vacancy created by the resignation of Joseph G. Magrath.

Mr. Plummer was born in 1900. He holds a Bachelor of Arts degree from Ohio University, a Bachelor of Science degree from Case Institute of Technology and a Master of Science degree from this same school. He is a registered engineer in the states of Ohio, New Jersey and New York. Mr. Plummer has written two books: *Statically Indeterminate Structures* and *Soil Mechanics and Foundations*. A third book, *Unfired Pressure Vessels*, is now in process. He is the author of more than thirty articles published in THE WELDING JOURNAL and other technical magazines.

Mr. Plummer was an instructor and associate professor at Case from 1923 to 1937, teaching mathematics, civil and structural engineering. In addition, he lectured at the Cleveland School of Architecture and at John Huntington Polytechnic Institute.

In 1928, while on leave from Case, Mr. Plummer was in charge of structural analysis and design of the world's largest airship dock for Goodyear Zeppelin Corp. at Akron, Ohio, in association with Wilbur Watson & Associates, consulting engineers and architects. He was also responsible for the design of a seven-million dollar steel bridge, while associated with Wilbur J. Watson and F. R. Walker.

During his stay at Case, he acted as consultant to a number of organizations, such as the Truscon Steel Co., Republic Steel Co., Dow Chemical Co., Lincoln Electric Co., Aluminum Company of America, the U. S. Army Corps of Engineers and others. From 1937 to 1940, Mr. Plummer was chief design engineer of the Main Avenue Bridge Projects in Cleveland. The project included the main bridge structure about one-mile long with complicated approach structures. It was necessary to wreck partially and remodel many buildings, as well as to move and reconstruct many sewer and utility lines. The complete project cost about eight-million dollars.

Since 1940, Mr. Plummer has been director of engineering of the Hammond Iron Works in Warren, Penna. This company fabricates and constructs all types of shop- and field-erected steel-plate structures and vessels used by the chemical, rubber and petroleum industries.

In addition, he was general manager of Hammond Latina Americana Construction Co., operating outside continental United States.

In 1950, Mr. Plummer was a member of the Bailey Bridge Mission to Japan. He headed a group of engineers and project managers sent to Japan by the Corps of Engineers, U. S. Army, following the outbreak of the Korean War, to assist Japanese manufacturers and fabricators of steel in setting up procedures and facilities for producing necessary special steels and in fabricating Bailey Bridge parts which would be interchangeable with those produced in the United States and Great Britain.

Mr. Plummer returned to Japan in April 1956. During this visit, he presented a talk before the Japan Welding Society, and was awarded an Honorary Membership in this group. He was the second foreign person to be so honored.

In February, 1953, Mr. Plummer received a citation from the Case Institute of Technology for "having distinguished the college and himself through outstanding achievement in his chosen field." He received a similar citation from Ohio University.

His AWS activities have been numerous. He served as chairman of the Cleveland Section, 1938–41; Director, 1941-44; District Vice President, 1948–50; and National President, 1952-54. Mr. Plummer has also served as chairman of the following AWS committees. Executive; Constitution and By-Laws; Honorary Membership; National Nominating; Past President, Advisory; Welding Handbook; Advisory Committee on Member Classes; and Organization Structure. In addition, he has been active as a member of the following committees; Code of Principles Conduct; Headquarters Housing; Reserve Funds; Rules for Field Welding Storage Tanks; Finance; and AWS-IIW. He is also Chairman of the Pressure Vessel Research Committee of the Welding Research Council.

Other professional organizations have also had the benefit of Mr. Plummer's services. His memberships include: the American Society for Engineering Education with whose Civil Engineering Division he served as national chairman in 1936-37; a past president and trustee of the Cleveland Engineering Society; the American Society of Civil Engineers; the American Society of Mechanical Engineers; the American Society for for Testing Materials; the American Petroleum Institute; the American Concrete Institute; the American Society for Metals; and the National Research Council. Honor societies include Sigma Xi; Tau Beta Pi and Phi Beta Kappa.

At the Adams National Meeting in Philadelphia, Mr. Plummer was awarded the Samuel Wylie Miller Memorial Award for "outstanding contributions in the application of welding to storage tanks to the advancement of engineering technology in the shop and field fabrication of welded structures."

8th District Section Conference

The *Iowa* Section of the AMERICAN WELDING SOCIETY will act as host to the 8th District Section Conference to be held July 20, 1957. Registration is scheduled for 9:00 A.M. at the Kirkwood Hotel in Des Moines, Iowa. Entertainment is planned for the ladies plus a dinner-dance to close the one day conference.

National Supply New Supporting Company

The National Supply Co., 3320 Bishop St., Toledo, Ohio, has recently become a supporting company of the AMERICAN WELDING SOCIETY. The authorization was made by R. H. Etnyre, works manager of the company.

De Laval Separator Co. Becomes Sustaining Member

The De Laval Separator Co., Poughkeepsie, N. Y., manufacturers of equipment for industry, milk plants and dairy farms, has become a sustaining member of the AMERICAN WELDING SOCIETY.

Industrial equipment consists of centrifugal separators, clarifiers and concentrators with applications in power, chemical processing, fish, food, marine, metal, vegetable, oil, paper and pharmaceutical fields.

Milk plant equipment deals with milk separators, milk clarifiers, pasteurizing equipment and butter churns.

Dairy farm equipment features milking machines, Combine Milkers, farm separators, bulk milk coolers and water heaters.

C. R. Purdy is the sustaining member representative.

Taylor-Winfield Becomes Sustaining Member

The Taylor-Winfield Corp., 1052 Mahoning Ave., N. W., Warren, Ohio, has assumed status as a sustaining member of the AMERICAN WELDING SOCIETY.

A manufacturer of electric-resistance and arc-welding equipment, Taylor-Winfield Corp.'s 50 years of experience combines research application, design and manufacturing facilities in the fields of standard and special spot, projection, seam and flash-butt welders; metal gathering machines; inert-gas shielded-arc and submerged-arc welding machines; electronic and electrical sequence controls; hydraulic and pneumatic apparatus; and mechanized work-handling equipment and metalworking processes associated with welding. Field sales and service are maintained in major cities throughout the United States and Canada. Sales representation is also maintained overseas.

T. S. Long is the sustaining member representative.

Metals Course at Wentworth

A new course in metals technology will be inaugurated at Wentworth Institute, Boston, this coming September, according to an announcement by H. Russell Beatty, Wentworth president.

The new course will be of two-years' duration and will lead to the degree of associate in engineering. Welding and brazing will be included in the curriculum.

Several members of the Boston Section, among them P. E. McKenna, AWS, were instrumental in the realization of the course.

DESIGN PAPERS

Papers dealing with the progress of welding in the field of *structural design* and *machine design* are solicited for the 1958 AWS National Spring Meeting in St. Louis, Mo. For proper consideration, manuscripts or 500-word abstracts, must reach AWS Headquarters prior to August 15, 1957. Send all manuscripts or abstracts to:

AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

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NEW ENGLAND GROUP MEETS WITH THEIR DIRECTOR

At a dinner meeting held on May 28 at the Maridor Restaurant in Framingham, Mass., Sidney Low, Director of District No. 1, met with officers representing the various sections within his District to discuss a number of items of AWS interest.

Those present at the meeting requested that Mr. Low campaign for the AWS Annual Convention to be held in Boston in 1961.

Allan Rosenberg of the Boston Section reviewed the mechanics of the Northeast Regional Welding Conference and of the success the Conference enjoyed. Mr. Rosenberg expressed the desire of the Boston Section to include all sections of District No. 1 to participate in the presentation of the 1957 conference. Representatives from all sections present offered their support to the problem. Mr. Rosenberg was then appointed temporary chairman of the 1957 New England Regional Conference.

It was also agreed that a District No. 1 council be formed which would include two representatives from each section and which would meet during the forthcoming regional conference on September 18, 1957.

The Boston Section acted as host for this special meeting and its chairman, Harvey Miller, presided.

Present at a dinner-meeting held on May 28 were, seated left to right, first row: Harry Udin, Sidney Low, Harvey Miller, Allan Rosenberg and Walter Ovaska; Second row: Hugo Stahl, Julius Ritter, William S. Naband, Ralph Gilbert; third row: J. C. Swann, Andrew Kokolski, Herb Turck, R. M. Rood, Cliff Murray and Helmut Thielsch; and fourth row: Frank Brandt and Bob Worrell

EAC DOINGS

Apprentice Training Group Furthers Progress of EAC

by H. A. Sosnin

The apprentice training subcommittee of the Educational Activities Committee participated in the recent Union-Industries Joint Show which was held during May 16–21 in Kansas City.

An innovation at the show was the appearance of a booth promoting the apprentice training program of the United Association of Plumbers and Pipefitters. The program was under the able direction of Joseph P. Corcoran, an active member of the AMERICAN WELDING SOCIETY's apprentice training subcommittee.

"Welding pipe" was the principal theme of the booth, which was manned by several members of the SOCIETY's committee.

H. A. Sosnin demonstrating oxyacetylene welding of small diameter pipe for Richard P. Walsh. Mr. Walsh is an apprentice coordinator for the United Association of Plumbers and Pipefitters

H. A. Sosnin, Chairman, Subcommittee on Extension Training and Apprentice Training, AWS Educational Activities Committee; associated with Tube Turns, Inc., Louisville, Ky.

Section News and Events

as reported to Catherine O'Leary

ELECTION OF OFFICERS

Boston, Mass.—The *Boston* Section announces the election of the following officers for the 1957–1958 term: chairman, Harvey S. Miller, New England Hard Facing Co.; 1st vice chairman, Walter A. Ovaska, Air Reduction Co.; 2nd vice-chairman, Harry Udin; Secretary, Andrew Kokolski, General Electric Co., Welding Sales Div., 150 Causeway St., Boston 14; treasurer, Albert R. Barilaro, Interstate Welding Supply Corp.

ANNUAL DINNER DANCE

Milford, Conn.—On Friday evening, May 17, the *Bridgeport* Section held its Annual Spring Dinner Dance. The affair was held at Donat's Town-Ho on the Boston Post Road in Milford, Conn.

There were twenty couples in attendance. Dinner started at 8:00 P.M. Ten door prizes were awarded to lucky winners. After dinner there was dancing. Everyone had an excellent time.

Past-Chairman Edward A. Staiano was honored with a past chairman's pin. The new slate of officers was announced as follows: chairman, Leo Lefkovitch; vice-chairman, Joseph Barker; program chairman, Robert Hirsch; secretary, Robert R. Monde; treasurer, Romeo A. Lalli; membership chairman, Raymond Moore; technical chairman, Joseph R. Skibo.

EXECUTIVES' NIGHT

Raleigh, N. C.—The monthly meeting of the newly formed *Carolina* Section was held on April 29 at Scandia Village Restaurant in Raleigh. This meeting was planned to bring together officials of state, government and plant management with the members of the Society; to promote a closer affiliation and understanding of each other's problems, how each can benefit by association, exchange of ideas to increase present industries and attract new industries to the State of North Carolina.

District Director Donald B. Howard, who is staff metallurgist for the American Car and Foundry Division, gave a talk on the advantages of membership in the Society for the individual and the employer, through publications and opportunities of sharing ideas with friends and competitors which increases production and reduces research time and costs. He also pointed out that membership in the Society has risen from 217 in 1919 to 12,000 in 1956.

Other speakers included Secretary of State, Thad Eure, who told the group that North Carolina was one of five states showing increases in business incorporations during January and February. G. F. Albright, head of the small industries section of the Department of Conservation and Development, led a group discussion, with emphasis being placed on how the welders can materially assist in helping promote the industrial development of the State. Another special guest was Fred B. Wheeler, Mayor of Raleigh.

DIGNITARIES ATTEND MEETING OF CAROLINA SECTION

Among those attending the April 29 meeting of the Carolina Section were, left to right: Donald B. Howard, director of District No. 2; Hon. Fred Wheeler, Mayor of Raleigh; Secretary of State Thad Eure, and Ralph Cope, Section chairman

WELDING PROCESSES

Chicago, Ill.—The *Chicago* Section paid honor to the outgoing AWS president by designating the April 21 meeting as Jack Chyle Night.

Mr. Chyle gave a brief talk on the current activities and accomplishments of National Headquarters.

Due to the sudden death of Lew Gilbert, who was scheduled to speak, a fine job of pinch hitting was done by O. T. Barnett (AWS), of the Armour Research Foundation, in a talk on "Welding Processes."

A pre-meeting movie, "1956 Golf Outing," was enjoyed by all since many members had an opportunity to see themselves on the screen.

Eighty diners were present for dinner at Milner's Restaurant; after which 125 members and guests met at the Peoples Gas, Light & Coke Co. Auditorium for the meeting.

WELDING PROCESSES

Denver, Colo.—Twenty members of the *Colorado* Section were present at a dinner meeting held in the Festival Room of the Oxford Hotel in Denver on May 14. Harry Huff (AWS), a welding specialist with the Air Reduction Sales Co., addressed the group on the subject of "General Welding Processes." His talk was very practical and instructive and was accompanied by slides. A very competent job on the slide projector was done by C. E. Reissig, a local Section member.

MAGNETIC-FLUX WELDER

Dayton, Ohio—The May 14 meeting of the *Dayton* Section was held at

Price Brothers Co.

The meeting was opened with a film entitled "Automatic Assembly Machines for Printed Electronic Circuits" and was shown through the courtesy of the United Shoe Machinery Corp.

The film was followed by a short discussion on the use and theory of the new "Manual Magnetic-Flux Gas-Shielded Arc Welder" by Culver Heffernon AWS. Mr. Heffernon is manager of the Engineering Services Department of Linde Co. in Indianapolis, Ind.

An actual demonstration of the use of the machine was given by D. F. Secrest AWS, also of Linde.

QUALIFICATION PROCEDURES

Appleton, Wis.—Fred E. Theiler AWS, welding instructor at the Madison Vocational School, was the guest speaker at the April 22 meeting of the *Fox Valley* Section. Mr. Theiler's talk covered both the qualifying of operators and the qualifying of procedures. He explained the reasons for such qualification and the steps necessary in each of the processes. The talk engendered a lively question and answer period which was stopped only by the late hour.

Before the meeting a sound color film, entitled "Welding Advances with Aluminum," was shown through the courtesy of the Aluminum Company of America.

INSTALLATION OF OFFICERS

Appleton, Wis.—The Annual Spring Dance and Installation of Officers of the *Fox Valley* Section took place on Saturday, May 11.

The dinner was preceded by a cocktail hour. At the conclusion of the dinner, Master of Ceremonies Bob Lloyd took over and entertained with a number of humorous sketches and stories. After a series of songs by a quartet, the new officers were introduced as follows: chairman, Ken Ligare; 1st vice-chairman, John Wiegand; 2nd vice-chairman, Ed Koch; secretary, Robert Hart, and treasurer, Thomas Krizensky.

The incoming chairman outlined the plans for the coming year and thanked the retiring officers for a job well done.

The evening was concluded with dancing. Some one hundred and ten members and guests attended.

FABRICATION OF T-1 STEEL

Houston, Texas—The largest turnout of members of the *Houston* Section for a technical session this year took place on April 24 when 115 were in attendance at dinner and a lively discussion led by Louis K. Keay AWS, and Lester K. Dawson AWS, of Lukens Steel Co. Mr. Keay is technical service engineer and Mr. Dawson is advisor to Lukens customers on welding and fabrication techniques applicable to Lukens clad and alloy steels.

The speakers' subject was "Fabrication of T-1 Steel." Mr. Keay did an outstanding job of familiarizing everyone in attendance on the chemical and physical properties of this relatively new steel. This was followed by a discussion of some of the problems to be expected in welding and forming the material.

RESISTANCE WELDING

Indianapolis, Ind.—The March 22 meeting of the *Indiana* Section was held at the Athenium Turners Club where approximately thirty members and guests were on hand for an excellent dinner.

Technical speaker for the evening was Robert Barley AWS, associated with B & G Automation Controls Corp. Subject of Mr. Barley's talk was "Resistance Welding and Design for Resistance Welding" and was illustrated with slides.

Covered were some of the more fundamental aspects of the various resistance welding processes and proper design for basically sound application of the processes was discussed. Many applications of poor and good design were illustrated. Mr. Barley also showed a sound and color film in conjunction with his talk.

QUIZ-THE-EXPERTS NIGHT

Indianapolis, Ind.—The April 26

AT KICK-OFF LUNCHEON SPONSORED BY LOS ANGELES SECTION

Approximately 345 members and guests attended the "kick-off" luncheon sponsored by the Los Angeles Section during the 10th Metal Congress. Among those present were John J. Chyle, AWS President 1956–57, and Clarence P. Sander, AWS President, 1957–58

meeting was the annual *Indiana* Section "Quiz the Experts" program. Leading off was a social hour for the reception of the competing sections. The dinner and meeting were at the Antlers Hotel with about 65 members and guests. Guest of honor and dinner speaker was John H. Bankenbuehler, director-at-large, who spoke on "Your American Welding Society."

The Indiana Section was host to four competing Sections for possession of the "Trophy." The competing Sections were: Anthony Wayne, Dayton, Detroit, and North Central Ohio. Detroit was the defending champion. Quiz moderator was Ray Wirt of the Indiana Section. The Anthony Wayne Section won the Trophy. Members of the winning team were: Harry M. Johnson, Captain; James McLain, George Laws, D. B. Rice and K. H. Zimmerman.

WELDING PROCESSES

Kansas City, Mo.—The meeting of the *Kansas City* Section held on May 16 was attended by forty-five members and guests, who were treated to a fine talk on "General Welding Processes," as given by Howard Huff AWS, of Air Reduction Sales Co.

Mr. Huff included some very interesting slides on inert-arc welding and his answers to various questions proved the scope of his experience in this and other fields.

Since this was the last meeting of the season, the ballots were tabulated and the new officers announced: chairman, B. G. Harrington, Air Reduction Sales; vice chairman, Delmar Burrows, Fluor Corp.; Secretary, J. F. Pritchard, Jr., Dover Manufacturing Co.; treasurer, J. R. Warn, Havens Structural Steel; directors, Clyde Hull, Jr., R. T. Howard, Walter Spencer.

The dinner and meeting were enjoyed by all and it was decided by unanimous vote to continue the meetings at the Golden Ox for the coming season.

WELDING PROCESSES

San Diego, Calif.—On May 3, ninety-eight members and guests of the *Los Angeles Aircraft and Rocketry Panel*, met once again for the fourth consecutive year at the Mission Valley Country Club in San Diego, to enjoy cocktails, dinner and an outstanding program produced by members in the San Diego area. This was known as "Convair Astronautics Night in San Diego."

The two principal speakers for the evening were W. P. McGregor AWS, tool development engineer for Convair and W. L. "Bill" Young, operations manager of Convair's new Astronautics Division.

Mr. McGregor presented an interesting paper on "Welding Processes" describing the inert-gas welding and resistance-welding equipment and fixtures as applied to the Atlas missile program.

Slides were shown of tungsten-arc welding on curved and vertical parts, and of resistance equipment as used to weld 290,000 spots on the Atlas missile. In concluding his paper, Mr. McGregor discussed some of their future research problems.

In presenting his talk on the Atlas missile, Mr. Young mentioned that the Astronautics Division was one of the newest divisions of Convair and was rapidly expanding both in personnel and buildings. A brief history of the missile was described which showed that the original design and testing was started in 1946 on the model MX774. However, in 1949 the Air Force cancelled the program and Convair was forced to continue the research on a limited basis. In 1953 a high priority was given to the program and Convair began building units in 1955.

AIRCRAFT PANEL MEETS IN SAN DIEGO

Seated at Speaker's Table, at the May 3 meeting of Aircraft and Rocketry Panel of Los Angeles Section, were, left to right, W. L. Young, W. P. McGregor and George Brolaski of Convair

Charles Smith, chairman of Los Angeles Section, reports on the warm welcome extended to the newly elected AWS President, C. P. Sander at the National Spring Meeting in Philadelphia

Mr. and Mrs. Sander were among the early arrivals at the Mission Valley Country Club where meeting was held

Miss Lottie Root assists Panel chairman Mario Ochieano in the drawing of door prizes

Both speakers were presented with desk pens in appreciation of their interesting presentation.

NONDESTRUCTIVE TESTING

Huntington Park, Calif.—The *Los Angeles* Section held its last technical meeting for the fiscal year on May 16 at the Elks Lodge in Huntington Park, with fifty-eight members and guests present. The speaker for the evening was C. E. Betz AWS, vice chairman of the Board of Directors, Magnaflux Corporation, Chicago, who presented a paper on "Nondestructive Testing in the Inspection of Welds."

Mr. Betz presented a general survey and discussion of various nondestructive test methods in use in the inspection of welds and some of the latest developments in the use of magnetic particle and penetrant inspection in the field of welding, details being disclosed of recent installations with the use of slides.

Mr. Betz was presented with a desk pen in appreciation of a job well done.

HARD SURFACING

Baltimore, Md.—The subject of

NONDESTRUCTIVE TESTING DISCUSSED BY BETZ

C. E. Betz was guest speaker at the May 16 meeting of Los Angeles Section. His subject was "Nondestructive Testing in the Inspection of Welds"

Section Chairman Chas. Smith, President C. P. Sander, S. R. Lanier and Leo M. West shown in get-together prior to meeting

Enjoying refreshments are Jack Riley, "Connie" Hogon, Joe Cye, Philip Deuchler, Earl Lund and Ralph Martin

the April meeting of the *Maryland* Section held on April 25 was well explained by Herb Clarke AWS, of Coast Metals, Inc., Little Ferry, N. J.

Mr. Clarke spoke on "Hard-Surfacing Alloys and Their Characteristics and Methods," describing various alloy electrodes and inserts used to reduce problems subjected to abrasion, corrosion and heat resistance. He also discussed developments in powder metals for hard surfacing.

David G. Baille of Singstad & Baille, engineers of many New York tunnels and other large projects and engineers of the Baltimore Harbor Tunnel Crossing, was the coffee speaker. Mr. Baille described the work on the tunnel and showed a number of slides showing the work as progressed to date.

LADIES NIGHT

Baltimore, Md.—The *Maryland* Section held the final meeting of the season on May 25 with a ladies night, second annual dinner dance and installation of officers for the coming season at the Southern Hotel in Baltimore, with music by Leroy Heinie and his Orchestra.

The following officers were elected for the 1957–58 season: chairman, C. H. Basel, Earlbeck & Landrum, Inc.; 1st vice-chairman, J. H. Burnley, Koppers Co. Inc.; 2nd vice-chairman, B. F. Jones, Southern Oxygen Co. Inc.; secretary, R. E. Metius, Bethlehem Steel Co.; treasurer, J. O. Benson, Bureau of Materials & Soils.

NEW OFFICERS

South Bend, Ind.—The *Michiana* Section met for their final session of the season on May 16. This meeting was the annual business-social get together. Announcement was made of the election of the following officers: chairman, Walter Wille, Oliver Corp.; vice-chairman, Verland Bloxson, Durakool Corp.; secretary, W. G. Fassnacht, Bendix Products; treasurer, Floyd Doolittle, Bendix Products.

Following the business session, the members vied for some door prizes and then enjoyed two movies. One, "The Chemistry of Fire," shown through the courtesy of the Indiana State Fire Marshall, should be seen by every welder.

ANNUAL DINNER DANCE

Manchester, N. H.—The first annual dinner dance of the *New Hampshire* Section was held on May 18 at Six Acres, Manchester. Fifty members, accompanied by wives and guests, enjoyed a cocktail hour that preceded a most delicious dinner.

Election of officers for 1957–58 followed the dinner, and the following were chosen to serve: chairman, J. C. Swann, New Hampshire Welding Supply; 1st vice-chairman, Robert Worrell, Lyons Iron Works; 2nd vice-chairman, Robert Tuttle, Public Service Co. of N. H.; treasurer, Albert Gilbert, Gilbert Welding.

Coffee speaker of the evening was Donald Quimbey who kept his audience in a hilarious mood with his endless collection of stories and anecdotes. Dancing completed the evening's program and it was the concensus that the committee did an outstanding job in making this affair the highlight of the Section's activities of the year.

MAGNETIC-FLUX WELDING

New Orleans, La.—The *New Orleans* Section held its final meeting of the year on May 21 at Watkins Broadview Restaurant, with 53 members and guests in attendance. Guest speaker was L. L. Kelly AWS, of Linde Co. His subject was "Union-Arc—Something New in Welding."

Mr. Kelly gave a fine lecture, as he usually does, on the above subject. Motion pictures and slides were used to demonstrate the processes and applications. Mr. Kelly also entertained a question and answer period.

NEWLY ELECTED OFFICERS

New York, N. Y.—At a meeting of the Executive Committee of the *New York* Section held on May 3 at Toots Shor Restaurant, the report of the Tellers Committee and the results of the election of officers for the fiscal year were announced as follows: chairman, A. L. Seiden; 1st vice-chairman, J. E. Mooney; 2nd vice-chairman, G. Metterhauser; secretary, H. D. Landis, Jr.; treasurer, M. D. Bellware.

MODERN STEELS

Mt. Vernon, Ohio—The May meeting of the *North Central Ohio* Section held on May 10 in Mt. Vernon, Ohio was a joint meeting with the Columbus, Ohio, Section. Fifty-seven members and guests enjoyed dinner at Mazza's Gourmet Room.

During the business meeting the new officers for 1957–58 were installed as follows: chairman, S. W. McDonald, Cooper-Bessemer Corp.; 1st vice-chairman, R. B. Leiter, F. E. Myers & Bro. Co.; 2nd vice-chairman, T. A. Long, Gar Wood Industries; secretary, R. W. Kennedy, Mineweld of Indiana; treasurer, O. C. Rowlinson, Ohio Locomotive Crane.

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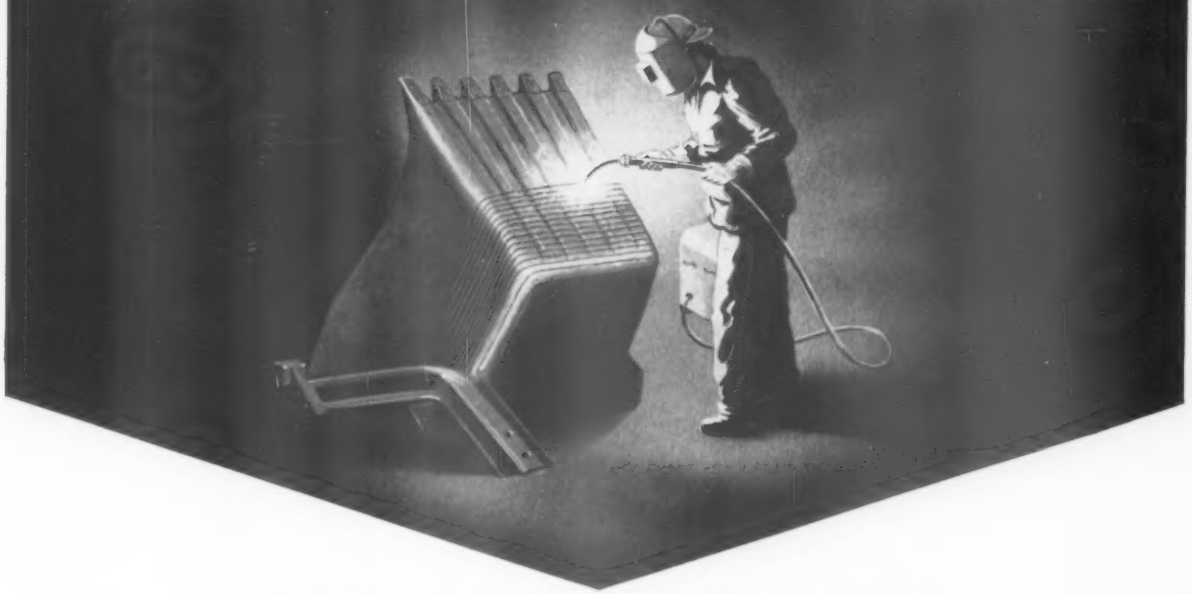

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THE WIRE MILL FOR THE WELDING INDUSTRY — STAINLESS STEEL · HARD SURFACING · TOOL STEEL

Speaker for the evening was Dr. W. D. Doty AWS, welding research engineer with the U. S. Steel Corp., Applied Research Laboratory in Monroeville, Pa. His subject was "Modern Steels and Their Weldability."

PLANT TOUR

Olean, N. Y.—The *Olean and Bradford* Section met on May 21 for dinner at the Olean House, after which a tour was made of the Turbo Products Division of Clark Bros., which was very interesting. Richard Voslamber, plant superintendent, spoke briefly on the new welding and fabrication plant that is being built and the new turbo engines that are being manufactured.

STEEL

Portland, Ore.—The April meeting of the *Portland* Section was addressed by Ted Carlson of the U. S. Steel Supply Co., who gave a nice talk on steel and showed some very interesting movies of their steel mill in action. This was followed by another movie on their operations in Venezuela.

STUDENT AWARDS

Saginaw, Mich.—The *Saginaw Valley* Section reported a new approach for stimulating the interest of high school students in welding. R. F. Woollard, chairman and W. F. Williams, vice-chairman, were instrumental in sponsoring special awards to student exhibitors at the Midland and the Flint Science Fairs. Two winners were selected from each city—one from the Junior and one from the Senior High School Division. The awards consisted of subscriptions to a scientific or a mechanical magazine selected by each winner. This initial venture was highly successful and the Saginaw Valley Section is looking forward to an increased interest in welding at the next year's Science Fairs.

AUTOMATIC WELDING

Shreveport, La.—The *Shreveport* Section met on May 16 at Captain Shreve Hotel for dinner and meeting.

Principal speaker was Phil Sackbauer, Pandjiris Weldment Co., St. Louis, Mo. Mr. Sackbauer related some history of the welding fixture industry which has paralleled the submerged-arc welding process. He pointed out that, today, there are 30,000 submerged-arc welding heads in operation out of the 66,000 that have been sold. The following are some of the things to be taken into consideration in regard to automatic welding:

(*a*) Product to be welded must lend itself to automatic welding or can be so designed.

(*b*) Operator may be important or he may just push a button to start completely automatic cycle.

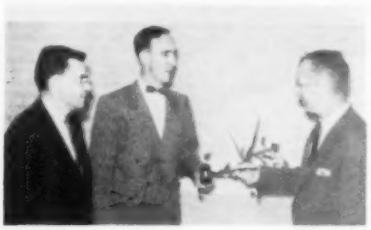
(*c*) Welding equipment—relative cost and speed will determine whether it will be semiautomatic or automatic.

(*d*) Fixture—determined by type and gage of material, production requirements, whether or not the parts are pretacked before loading, whether there are locating points for loading, space limitations, amount of automation desired and work employment having to do with moving part in relationship to head or head-to-work.

DOTY SPEAKS ON WELDABILITY OF STEELS

General view of the members and guests present at the joint meeting of the North Central Ohio Section and Columbus Section held on May 10 in Mt. Vernon, Ohio

Seated at head table are Solon McDonald, incoming chairman of North Central Ohio Section; W. D. Doty, guest speaker; Howard Cary, outgoing chairman of North Central Ohio Section, and J. J. Vagi, vice chairman of Columbus Section



Mr. Cary is shown handing the traditional chairman's gavel to Mr. McDonald, while Dr. Doty looks on. Dr. Doty's topic was "Modern Steels and Their Weldability"

ELECTION OF OFFICERS

Miami, Fla.—The *South Florida* Section announces the election of the following officers for the 1957–58 fiscal year: chairman, Herbert J. Hoodwin, City of Miami Building Dept.; 1st vice-chairman, Robert B. Banning, Consulting Engineer; 2nd vice-chairman, Clement H. Echtle, Treas. Dept., USCG; secretary, Thomas R. Berg, J. Calvin Juriet & Assoc.; treasurer, Leo R. Riedy, Jorgensen & Schraffler.

As announced in the June issue, this Section is holding Open Meetings on the third Wednesdays of June, July and August, to discuss the activities, welfare and management of the Section. These will be held at the new meeting place—Miami Firemen's Benevolent Association's Hall, 2980 N.W. South River Drive, 2 blocks west of 27th Ave. Bridge on the Miami River. Regular meetings will start in September on the third Wednesday of each month, up to and including May 21, 1958.

MAY DINNER DANCE

Toledo, Ohio.—The sixth annual dinner dance of the *Toledo* Section was held on Saturday, May 18 at the Toledo Edison Club with 110 members and guests. Following a delicious Rock Cornish Hen dinner, the new officers were presented as follows: chairman, T. F. Ellis, Willys Motors, Inc.; 1st vice chairman, R. H. Hoefler, Kaighin & Hughes, Inc.; 2nd vice-chairman, M. Baughman, Air Reduction Sales; secretary, W. Morrison, Standard Oil Co.; treasurer, E. J. Morrison, Sun Oil Co.

The group was then entertained until midnight by dancing to the music of Al Shank, and refreshments were served.

In reviewing the past year, it was quite obvious to the Section members that all of its officers had put in con-

Toledo Section Chairman T. F. Ellis

siderable effort. Meetings were arranged for the purpose of teaching welding. The Section held an inert-gas welding clinic which was a great success, and also held its first "Stump the Experts" night. Although the increase in membership did not meet the intended goal, membership attendance at meetings was increased 100% over last year and the ground work for a sound Section and future expansion was firmly set. The members and officers can point with pride to past chairman Walter Schmidt for a job very well done.

WELDING PROCESSES

Wichita, Kans.—The *Wichita* Section met on May 15 at the Hickory House for dinner and meeting. Guest speaker was Harry Huff AWS, of Air Reduction Sales Co.

Mr. Huff spoke on the application of the automatic inert-gas tungsten-arc welding process, placing special emphasis on fixtures and jigs. He used slides to illustrate the various points in his talk. He also drew examples from actual applications in industrial plants. Mr. Huff's talk was informative and very interesting, and was followed by a very active discussion period.

ARC CUTTING OF METALS

Worcester, Mass.—The March meeting of the *Worcester* Section was held on March 4 at Nick's Grille. Speaker of the evening was John Douglass AWS, New England Manager, Linde Co., Boston. Mr. Douglass explained how, with the arc and the proper inert-gas envelope, it was possible to cut heavy aluminum, stainless and kindred metals. This lecture was illustrated with slides of various applications and setups. His audience was very attentive, asked numerous questions and gave the speaker enthusiastic applause.

IRON-POWDER ELECTRODES

Worcester, Mass.—The April meeting of the *Worcester* Section was held on April 1 at Nick's Grille. Speaker was William Troy AWS, district manager, Alloy Rods Co., York, Pa. His subject was "Iron-Powder Low-Hydrogen Electrodes."

Mr. Troy discussed the properties of iron-powder low-hydrogen electrodes as well as the application. He compared them with the conventional E6010, E6011 and E6012 rods and the conventional low-hydrogen rods available for some time. He pointed out that higher welding currents can be used with the iron-powder electrodes. When welding in the vertical position they will deposit weld metal at a much faster rate than the E6010 electrode when it is used at optimum current. Also that 1345 5/32-in. diam. iron-powder low-hydrogen electrodes when burned to 2-in. stubs, will deposit 100 lb of weld metal. The speaker stated,

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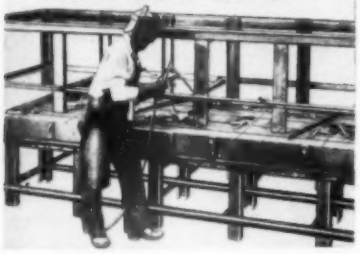

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in addition, that the welder technique involved with low-hydrogen iron-powder electrodes, is much less exacting than that required with the conventional low-hydrogen electrodes.

PLANT VISIT

Groton, Conn.—On April 18 the *Worcester* Section, in conjunction with other Sections in this area, Boston, Springfield and Bridgeport, participated as guests of the Hartford Section in a visit to the plant of the Electric Boat Co. at Groton, Conn.

This plant, a division of General Dynamics Corp., is the place where the atomic submarines "Nautilus" and "Sea Wolf" were built. The Worcester Section appreciated the honor of this invitation so highly that it hired a special train from the New Haven Railroad to transport 86 of its members and friends.

The visitors were privileged to see some of the most modern methods and positioning equipment known to the welding industry. An afternoon spent in this plant was a revelation to all those fortunate enough to be there. After the visitation, a cocktail hour and dinner at the "Meadows" rounded out the afternoon. In the evening, a

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speaker from the company explained a number of the operations and methods seen earlier.

BATTLE OF THE SECTIONS

York, Pa.—The final meeting of the season of the *York-Central Penna.* Section was held on May 7 at the Lincoln Woods Inn.

A quiz program, sponsored by the York-Central Penna. Section, was composed of teams from the following Sections: Philadelphia—Fred Judelsohn, Hallock C. Campbell, Walter Mehl; Susquehanna Valley—Al Belford, J. M. Cameron, Elwood Baucker; Lehigh Valley—A. T. Bavaria, C. L. Kreidler, R. D. Stout; York-Central Penna.—Luther Kemper, William DeLong, Lou Ames.

The moderator was E. B. Lutes of the Baltimore Section. The three judges were also supplied from the same Section.

The Lehigh Valley Section team was the winner. Members of the winning team were presented with AWS lapel emblems.

The newly elected officers were announced as follows: chairman, A. F. Leach; vice-chairman, E. R. Szumchowski; secretary, V. L. Woodward; treasurer, C. W. Allen.

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August 15, 1957 is Deadline for Sixth AWS National Spring Meeting Abstracts

Papers dealing with latest developments in (1) fabrication and maintenance of equipment used for radioactive applications, (2) brazing, (3) welding of dissimilar metals, (4) machinery design and fabrication, (5) automation as applied to resistance welding, inert-arc welding and other welding processes, (6) welding of castings and composite structures, (7) welding of plastics, (8) soft soldering, (9) equipment and transmission lines used in petroleum industry, (10) structures and railroads, (11) magnesium, zirconium, molybdenum and like metals and (12) practical applications or "how-to-do" topics are deemed to be of particular interest at the St. Louis meeting. However, any papers dealing with the educational and informative categories of welding production, engineering, research and metallurgy are welcomed as long as the subject falls within the field of our SOCIETY's activities.

To assure consideration for the 1958 National Spring Meeting Program abstracts must reach AWS not later than Aug. 15, 1957. Application forms, if needed, may be obtained by writing to National Secretary, AMERICAN WELDING SOCIETY, 33. W. 39th St., New York 18, N. Y.

Current Welding Literature

For copies of articles, write directly to publications in which they appear

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Watchdog on mounting costs

PRICES of common materials keep going up. Many new alloys are costly. Hence, rough castings become more expensive.

Even more, the cost of machining time keeps mounting. No one can afford to have it wasted by waiting for the tool to locate a void or defect.

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ABSTRACTS OF CURRENT PATENTS

prepared by Verne L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,778,925—Electrical Discharge Cutting Machine—John G. Gross and Henry Gill, Cincinnati, Ohio, assignors to the Cincinnati Milling Machine Co., Cincinnati, Ohio, a corporation of Ohio.

In this patent, a specialized machine for trepanning holes or slots in a work surface by electrical discharges is disclosed.

2,778,926—Method for Welding and Soldering by Electron Bombardment—Wilhelm Schneider, Frankfurt-am-Main, Germany, assignor to Licentia Patentverwaltungs G. m. b. H., Berlin-Grunewald, Germany.

This welding method is for producing systems having a unidirectional electric conductivity. A crystal means from the group comprising silicon and germanium and a contact means are placed in contact with each other and surface portions are joined to the contact means by bombarding such surface portions by electrons. This bombardment is such as to heat these surface portions and produce a permanent connection between the surface layer portions of the contact and crystal means.

2,778,927—Welding Rod Holder—William Martin Warren, Dallas, Tex.

This novel welding rod holder includes a tubular frame member having a pair of parallel arms at the forward end of such frame member. A wheel is disposed between these arms and has a diametrical opening therein for receiving a welding rod therein. Special control means complete the welding rod holder.

2,778,928—Welder's Helmet and Arc-Current Controlling Apparatus—Edward S. Morrell, Chippewa Falls, Wis., assignor to George Toebe, Chippewa Falls, Wis.

This patent covers the combination of a welding helmet with a movable shutter and an arc circuit controlling apparatus. The apparatus includes an electromagnet for moving the shutter into an eye protecting position after which a second electromagnet will close the main switch in the arc welding circuit.

2,779,674—Method of Removing Copper from Brazed Joints—Arthur T. Cape, Los Angeles, Calif., assignor to Superweld Corp., North Hollywood, Calif., a corporation of California.

Cape's special method is for treating copper-brazed steel parts to dissolve the copper without attacking the steel. The method includes the step of treating the parts with nitric acid and a solution containing gold ions in an amount effective to inhibit the attack of the steel.

2,779,857—Arrangement for Machining Conductive Material Through Electric Discharges—Nicolas Mironoff, Geneva, Switzerland, assignor to Ateliers des Charmilles S.A., Geneva, Switzerland, a corporation of Switzerland.

This apparatus performs a machining action by successive spark discharges and it includes a storage condenser adapted to discharge when an electrode and a workpiece connected thereacross are separated by an insulating medium. The circuit includes servo means for controlling the spacing between the electrode and the workpiece in such a manner that the voltage drop across the servo means is dependent upon the actual discharge voltage of the condenser. The servo means responds to any variation in the voltage drop across the electrode and the workpiece brought about by increase or decrease in the spacing between these members.

2,779,858—Method of Producing Metallic Ribbon Attaching Element and Welding the Same—Albert F. Pityo, Cedar Grove, N. J.

This patent relates to a specialized method of forming metallic ribbon-shaped attaching elements and securing them to a metal part.

2,779,859—Stud Welding Device—Thomas E. Shoup, Amherst, and Roger W. Sholle, Lorain, Ohio, assignors to Gregory Industries, Inc., Detroit, Mich., a corporation of Michigan.

An electric circuit for a stud welder is disclosed in this patent and such circuit is adapted to lift a stud from a workpiece to draw an arc therebetween. The circuit includes a first circuit with a lifting coil therein for lifting the stud from the plate and striking an arc therebetween, and a second circuit is provided to maintain the welding arc between the stud and the plate and it includes a holding coil to maintain the stud in a lifted position. A control circuit is operatively connected with the first and second circuits to maintain energization of at least one of the coils to keep the stud lifted while effecting de-energization of the welding arc.

2,779,861—Feeding-Device for Conducting-Wires, Especially Designed for Heating and Drying Coating-Materials Applied to Welding Rods—Harold Strohmeier, Kapfenberg, Steiermark, Austria.

This patent relates to a device for temporarily applying electric current to each of a succession of conducting members. The device includes an endless belt conveyor for carrying a succession of conducting members and two endless contacting belts disposed on opposite sides of the belt conveyor. Each of these contacting belts includes a series of mutually insulated electrically conducting contact parts. Other means are provided for applying current to mutually opposite contact parts as they are contacting each of the conducting members.

2,779,999—Method of Copper Brazing—Willard M. Boam, Fairlawn, and Herman H. Hanink, Ridgewood, N. J., assignors to Curtiss-Wright Corp., a corporation of Delaware.

The patent relates to fabricating a structure from a plurality of steel parts containing between 0.5 and 5.0% of chromium. First the entire surface of each of the parts is plated with nickel and the nickel plated surfaces of the parts are placed in substantially abutting relation with a clearance therebetween of approximately 0.001 in. Thereafter the surface portions are brazed together at a temperature of at least 2000° F.

2,780,194—Internal Back-Up Clamp for Girth Welding—Althos M. Croswell, Shreveport, La., assignor, by mesne assignments, to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

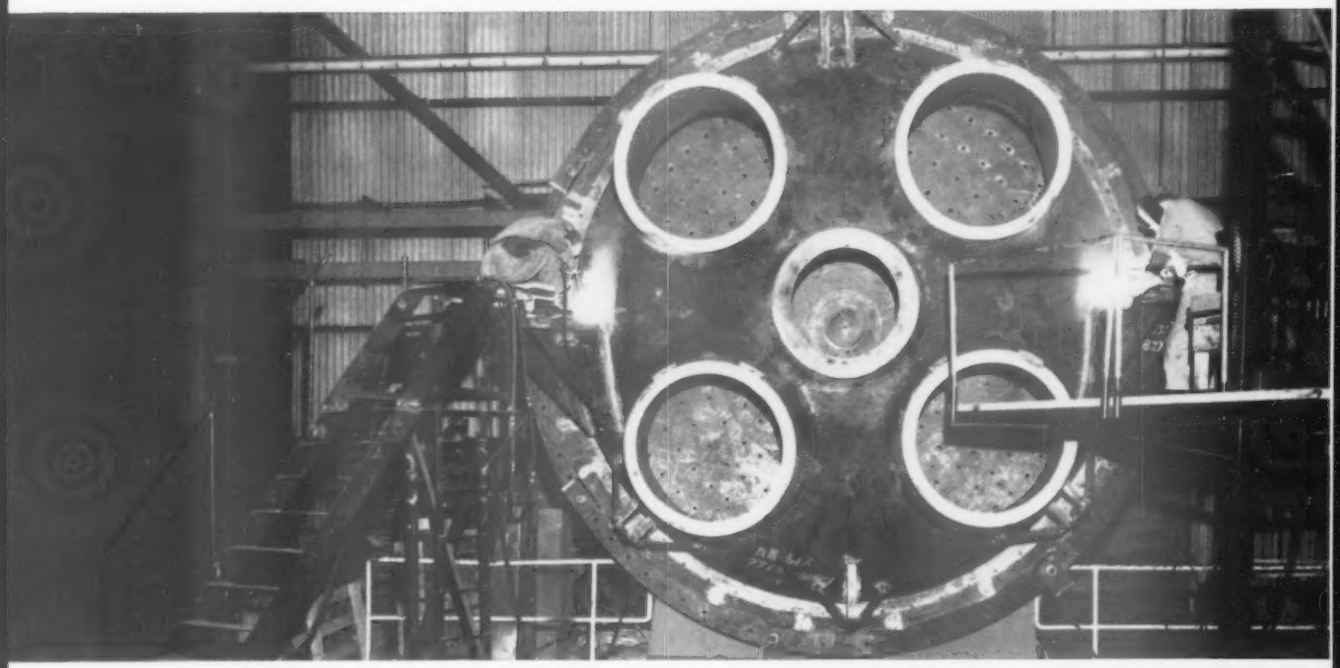
This patent relates to an internal aligning clamp for use in welding the joint between adjacent ends of two tubular sections. The clamp includes backing shoes and chill segments adapted to be brought into tight engagement with the inner surface of the tubular sections.

2,780,716—Core Manufacture—Michael E. Wasilisin and Donald E. Wernz, Baltimore County, Maryland, assignors to the Glenn L. Martin Co., Middle River, Md., a corporation of Maryland.

The present patent relates to a method of making seam-welded honeycomb cores. The method comprises the steps of placing a section of corrugated metal foil on a set of spaced, horizontally disposed fingers of electrically conductive material so that the lower portions of the corrugations extend down between the fingers while the upper portions of the corrugations rest on the fingers. A second set of fingers are placed in the lower portions of the section of corrugated metal foil on the first fingers and a second section of corrugated metal foil is placed on the second set of fingers so that the lower portions of the second section are in alignment with and contact the upper portions of the first mentioned section. Thereafter a welding current is passed through the sections to weld them together.

NEW Atom•Arc DH-12

IRON POWDER LOW HYDROGEN ELECTRODES FOR DOWN HAND WELDING



NEW ATOM•ARC DH Electrodes deposit up to 12 pounds of weld metal per hour with X-ray quality and physical properties equal to class E-7016 electrodes.

Just imagine, the visibility and flexibility of metallic arc welding with welding speeds and deposition rates comparable to semi-automatic submerged arc welding . . . and without messy fluxes or cumbersome equipment to handle. These advantages are yours with these *new* electrodes.

ATOM · ARC DH-9 FOR DOWN HAND WELDING AND HORIZONTAL FILLETS deposits X-ray quality weld metal at the rate of 9 pounds per hour at 300 amps. Burn off rate is 12.4 inches per minute.

ATOM · ARC DH-12 FOR DOWN HAND WELDING deposits X-ray quality weld metal at the rate of 12 pounds per hour at 360 amps. Burn off rate is 11.9 inches per minute.

• • • • • **Mail coupon today for complete facts ►**

Please send me the facts on Atom · Arc DH Electrodes.

DH-6

Alloy Rods Co.

ALLOY RODS COMPANY
P. O. Box 1828, York, Pennsylvania

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Title _____

Company _____

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NO FINER ELECTRODES MADE . . . ANYWHERE

NEWS of The Industry

Union Carbide and Three Divisions Change Names

The name of Union Carbide and Carbon Corp. has been shortened to Union Carbide Corp. Stockholders approved this change at the Annual Meeting of the corporation on April 16th.

The names of three divisions of Union Carbide have also been changed. Carbide and Carbon Chemicals Co. has become Union Carbide Chemicals Co.; Linde Air Products Co. is changing its name to Linde Co.; and Carbide and Carbon Realty Co. will be known as Union Carbide Realty Co.

New Research Director

The British Welding Research Association has announced that Richard Weck has been appointed director of research.

Dr. Weck is perhaps most widely known for his work on the fatigue properties of welded joints. He is also chairman of the commission of the International Institute of Welding which deals with residual stresses in welded structures.

Western Warehouse

The opening of a new western warehouse has been announced by All-State Welding Alloys Co., Inc., at 4933 Firestone Blvd., South Gate, Calif. The new facility was established April 1, 1957, and will handle the complete line of All-State's alloys and fluxes. It is under the direction of Harry Peacor.

New Gas Plant

The first commercial oxygen manufacturing plant in Mississippi was opened on May 15th by the National Cylinder Gas Co.

The facility, which will also produce acetylene and nitrogen, is located in the Flowood industrial area of Jackson, adjacent to the mill of the new Mississippi Steel Corp.

Fred C. Heppel, vice-president in charge of NCG's southern division, said oxygen will be piped directly to the Mississippi Steel Corp. The NCG plant will also serve dealers and provide direct bulk oxygen delivery service to industrial users and hospitals throughout central Mississippi.

ASTM Meeting

The 60th Annual Meeting of ASTM was held June 16–21 at Atlantic City. The Chalfont-Haddon Hall was convention headquarters where 32 sessions were presented on 13 varied fields of material technology.

AFS Elects New Officers

At the annual business meeting on May 8th in Cincinnati Harry W. Dietert and L. H. Durdin were elected, respectively, to the offices of president and vice-president of the American Foundrymen's Society. Elected to serve three-year terms as directors were Henry C. Stenberg, A. A. Hochrein, William D. Dunn, Fred J. Pfarr, Karl L. Landgrebe, Jr., John H. Russo and Allen M. Schlichter.

Airco Schedules Plant Expansion

Plans for a $3,000,000 expansion that will more than double the production facilities for gaseous and liquid oxygen at Lorain, Ohio, have been announced by John A. Hill, president of Air Reduction Co.

The expansion will boost daily capacity from the present 985,000 cu ft to 2,235,000 cu ft upon completion.

Construction of the addition to the Lorain plant is expected to be under way by July, and will take about a year to complete. It is part of Airco's $24,000,000 general expansion program for 1957.

Rex Welder Co. Acquired by Peer, Inc.

All assets of Rex Welder Co., Kansas City, Mo., have been acquired by Peer, Inc., Benton Harbor, Mich., producers of heavy-duty, automatic high-production resistance, welding equipment and standard resistance welders.

President Alton B. Parrott of Peer, in announcing the acquisition, said his company's production facilities have been doubled as a result.

Manufacturing and engineering facilities now are concentrated at Benton Harbor. Peer will continue to market welding equipment under both brand names: Peer and Rex, and no changes are planned in existing distributor organizations.

WELDED STEEL IGLOO

This huge steel igloo is actually an atomic energy reactor housing fabricated and erected by U. S. Steel's Consolidated Western Steel Division for the General Electric Co. Vallecitos atomic electric power plant near Pleasanton, Calif.

When the atomic reactor is enclosed in the big steel shell, it will produce heat to be transmitted to water, creating steam to drive a 5000 kw turbine.

Consolidated Western workmen at South San Francisco fabricated 275 tons of steel for the protective enclosure, on a contract from the Bechtel Corp. Every inch of weld underwent X-ray inspection in the field.

COMING EVENTS

A Calendar of Welding Activity

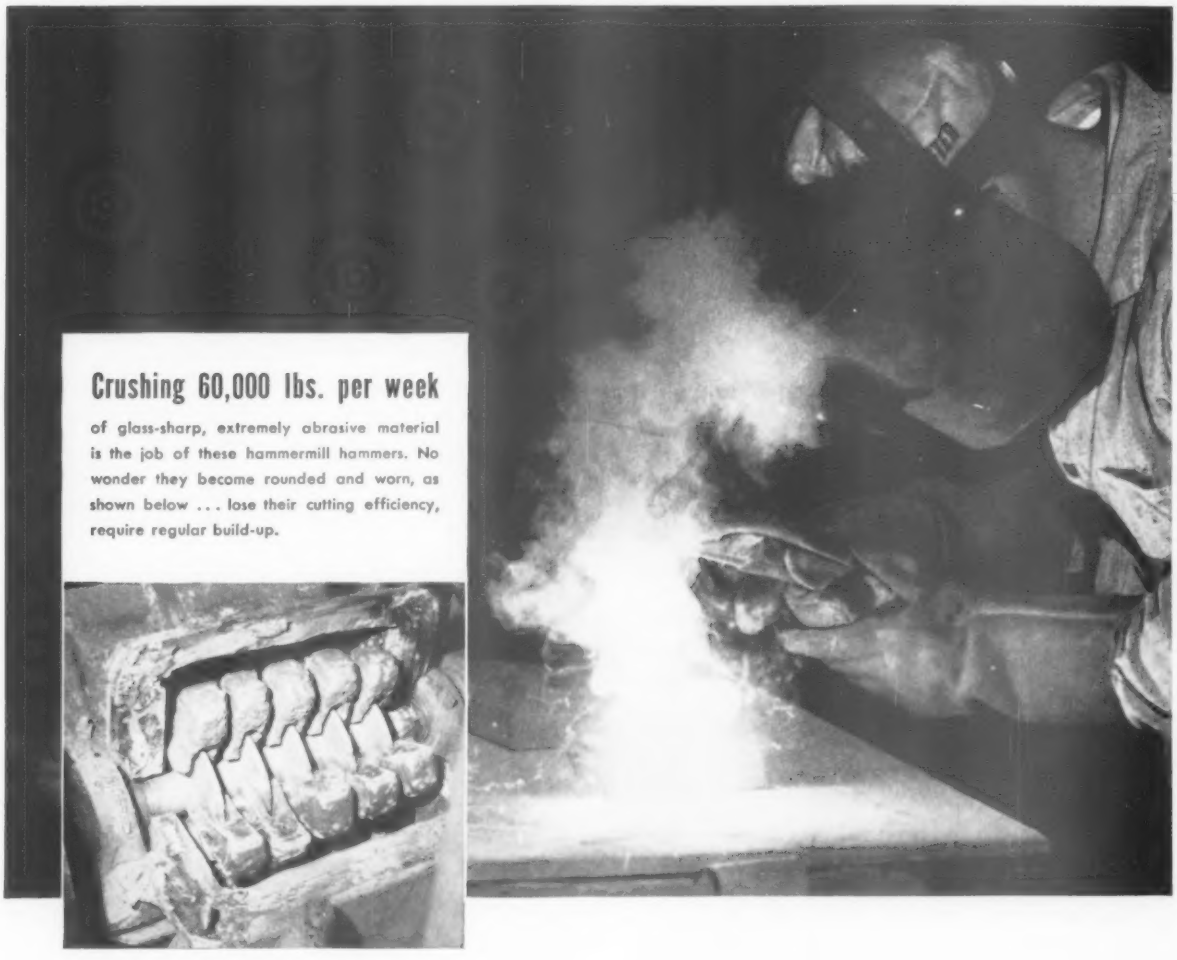
AWS National Meetings

1958 Spring Meeting and Welding Show:

April 14–18, Statler Hotel, St. Louis, Mo.

ASM

Nov. 4–8, 1957. Thirty-ninth National Metal Exposition & Congress, concurrently with Second World Metallurgical Congress, International Amphitheatre, Chicago, Ill.



Crushing 60,000 lbs. per week

of glass-sharp, extremely abrasive material is the job of these hammermill hammers. No wonder they become rounded and worn, as shown below . . . lose their cutting efficiency, require regular build-up.

HARDFACING WITH AMSCO® SUPER HF-20

doubles service life . . . cuts electrode costs

Welding Flux Processing, Chicago Heights, Illinois, know a good thing when they see one. That's why they've switched *exclusively* to Amsco Super HF-20 Electrodes for hardfacing of these hammers. They're saving three ways:

1. Service life of the built-up hammers and the mill housing itself has been doubled, because of Super HF-20's high abrasion resistance.
2. Super HF-20 electrodes cost about 40% less than the type previously used.
3. Welding speed is stepped up. Super HF-20, an iron powder "contact" electrode, is easy to handle and gives a high deposition rate.

In this and many other severely abrasive applications, Amsco Super HF-20 has *proved* its ability to provide superior wear resistance at low cost. Available from stock in 3/16" diameter, to handle hardfacing jobs of almost any size.

Call your nearby Amsco Welding Distributor now for a demonstration of Super HF-20. Or write direct for technical data to: Amsco Welding Department, Chicago Heights, Ill.

Amsco Welding Products distributed in Canada by Canadian Liquid Air Co., Ltd.

AMERICAN Brake Shoe COMPANY

AMSCO

American Manganese Steel Division • Chicago Heights, Ill.

OTHER PLANTS IN: DENVER, LOS ANGELES, NEW CASTLE, DEL., OAKLAND, CAL., ST. LOUIS, JOLIETTE, QUEBEC

NWSA Convention Acclaimed

The National Welding Supply Association held its thirteenth annual convention at the Hotel Mayflower, Washington, D. C., from May 13th through the 16th. Six hundred and twenty-five distributors and manufacturers were on hand to elect R. P. Tarbell, AWS, president for the coming year. Mr. Tarbell is the president of Scott-Tarbell, Inc., Cleveland, Ohio.

Delegates enjoyed three business sessions, panel discussions, the Eighth Annual Contact Booth Program in which 99 manufacturers participated and numerous social functions.

The six Zone Vice-Presidents elected are: A. C. Axtell, AWS, Essex Welding Equipment Co., Inc., Newark, N. J.; A. G. Thompson, AWS, Miami Welding Supply Co., Miami, Fla.; R. William Metzger, AWS, Compressed Gases (of Ohio), Inc., Cleveland, Ohio; R. S. Mars, Jr., W. P. & R. S. Mars Co., Duluth, Minn.; J. R. Stewart, AWS, Hill Equipment & Supply Co., Dallas, Tex.; George M. Avery, Scott-Foster Ltd., Vancouver, B. C., Canada.

The new Directors, with terms expiring in 1960 are: W. P. McLendon, Keenan Welding Supplies Co., Albany, Ga.; W. T. Hart, AWS, Valley Welding Supply, Inc., Appleton, Wis.; Charles W. Berry, AWS, General Welding Supply Corp., Mineola, N. Y.; Charles E. Squibb, AWS, Welders Supply, Inc., Dallas, Tex.

Senator William A. Purtell of Connecticut gave the keynote address in which he emphasized the importance and value to be derived from close manufacturer-distributor relations.

"Brother, you haven't welded till you've tried this New SW2-M— in any position!—

EVEN VERTICAL DOWN!"

It's the greatest development in E-6013 electrodes since that great, original Westinghouse SW!

This new SW2-M has *extraordinary* arcing characteristics—*excellent* bead shape!—*effortless* slag removal! —*really* low splatter loss! It's the easiest handling electrode *ever!* More than that, *every operator who tries it* says, "The new SW2-M is *great!*"

"No kidding—you, too, will *have to weld* with this one to believe it! I promise you a big surprise when you weld with the new, Westinghouse SW2-M!"

NEW SW2-M ELECTRODES NOW IN STOCK! READY FOR IMMEDIATE SHIPMENT! Call in your order *today*...you'll *weld better tomorrow!*

J-22081

ONLY WESTINGHOUSE OFFERS THIS WELDING LEADERSHIP

YOU CAN BE SURE...IF IT'S Westinghouse

New Company

A new welding supply company has been formed through the partnership of Frank Romano, AWS, and Jack L. Tanner, AWS. The company is known as Tanro Welding Alloys Co. and is

Frank Romano

J. L. Tanner

located at 194 Stone Ave., Yonkers, N. Y. Mr. Romano, who was formerly chief welding instructor for Eutectic Welding Alloys Co., announces that they will handle a full range of equipment, electrodes, gas rods and accessories. Mr. Tanner has been associated with the welding industry for many years. During the past ten years he has concentrated on distribution.

Industrial Expansion

A program calling for expenditure of approximately half a million dollars by Gregory Industries, Inc., at its Nelson Stud Welding plant in Lorain during the coming year has been announced by George E. Gregory, president

This program will include building additions which will increase Nelson's available floor space at Toledo Ave. and 28th St. by nearly 50%.

Other expenditures authorized by directors of Gregory Industries last week include a substantial outlay to meet the greatly expanded power requirements of the enlarged plant and to provide in-

creased production equipment and tooling for a new lightweight stud welding gun which is expected to open up important new markets for Nelson products. According to Mr. Gregory, the entire program will be financed from retained earnings.

Airco Dedicates $7,500,000 Facility

In dedication ceremonies held on May 27th, Air Reduction officially started production of liquid oxygen, nitrogen and argon at its new multimillion dollar air separation plant just completed at 119th St. and Doty Ave. in the Lake Calumet section of Chicago.

The ceremony was preceded by a guided tour through the plant, tracing the process by which the elements of the air are individually separated and purified.

Attending the affair were local city officials, executives from Chicago-area firms and Air Reduction officials from New York and Chicago. Among them were Ninth Ward Alderman R. DuBois and D. B. Jenks, president of the Chicago Rock Island & Pacific Railroad Co., both of whom welcomed Air Reduction and commented on the company's contribution to the growth of the Lake Calumet industrial area.

New multimillion dollar air separation plant opened in Chicago on May 27th

John A. Hill, president of Air Reduction Co. (*extreme left*), throwing switch to start the new plant. R. Du Bois, 9th ward alderman, and D. B. Jenks, president of Chicago Rock Island & Pacific Railroad Co. are looking on

John A. Hill, president of Air Reduction Co., Inc., commented on the tremendous growth ahead in the midwest metalworking industries. He also pointed out that the new plant has been designed so that it can be readily expanded. At the conclusion of the ceremony, Mr. Hill threw the switch that put the plant "on stream." The plant, including related distribution facilities, cost in excess of $7,500,000 and is of completely modern design with push-button operation from an electronic control panel.

This plant—which will produce daily 55 tons of high purity liquid oxygen, 15 tons of liquid nitrogen and 3½ tons of liquid argon—is the third large air separation plant completed by the company. Air Reduction already operates plants for the production of liquid oxygen, nitrogen and argon at Butler, Pa., and Riverton, N. J., and will soon complete construction of similar air separation plants at Los Angeles, Calif., and at Acton, Mass.

Motion Picture on Aluminum

Aluminum is spectacularly presented in its role as the "chameleon of metals" in the latest addition to Aluminum Company of America's library of sound motion pictures.

For 18 eye-filling minutes, viewers follow a "Man on a Skyhook" through a fantastic Dali-dream of form, color and texture in a myriad of hues. Appeal of the movie is tremendously imaginative as it portrays today's practicalities and tomorrow's possibilities of design with the light metal.

Movie is especially contrived to illustrate aluminum's versatile color and texture possibilities to designers, architects and engineers.

Narrated by Walber Abel, the film is in 16-mm sound, with a 35-mm. Eastman color negative available. Organizations desiring to borrow the film should write Motion Picture Section, Aluminum Company of America, 1501 Alcoa Building, Pittsburgh 19, Pa.

Growth Pattern Reflected in Resistance Welding

In a survey just completed of its 18 members, the Resistance Welder Manufacturers' Association figures covering the ten-year period from Dec. 31, 1946 to Dec. 31, 1956 show that capital investment has more than doubled. At the beginning of 1947, invested capital in this segment of the industry totaled $61/2 million dollars whereas this figure is currently about $14 million dollars. In 1956, shipments went up 39% and new business increased 21%. Manufacturing facilities have grown from 528,000 sq ft in 1946 to the present 812,000 sq ft. During the same decade the number of employees has increased from 2000 to nearly 3000.

The members of the RWMA have consistently in the early months of 1957 expressed an optimistic view of the immediate future of the resistance welding industry.

NCG Elects Corporate Officers

Directors of National Cylinder Gas Co. have elected vice-president James W. Dunham to the newly formed post

James W. Dunham

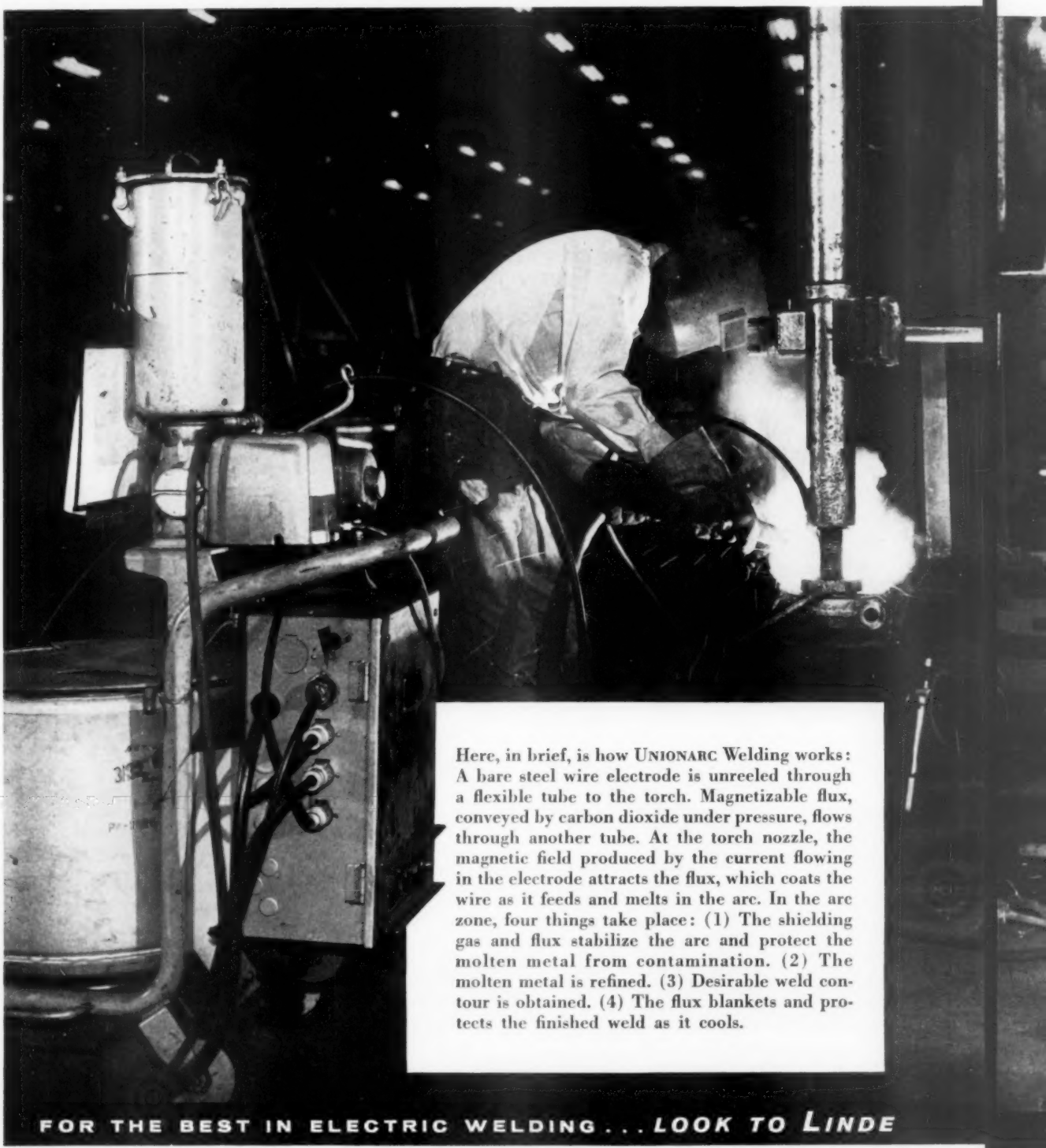
W. W. Whitnell

of chairman of the finance committee and elected secretary and controller W. W. Whitnell as a vice-president of the corporation, according to Charles J. Haines, president.

Mr. Dunham joined National Cylinder Gas Co.'s predecessor, the Keith Dunham Co., after his graduation from MIT in 1926 and has served continuously with the present company, where he has been in charge of production, engineering and research. He is president of the Compressed Gas Association and a past president of the International Acetylene Assn.

Mr. Whitnell graduated from the Chicago Law School in 1926, joined National Cylinder Gas Co. in 1943 as controller and was elected secretary in 1946.

Now... LINDE offers you another UNIONARC Magnetic



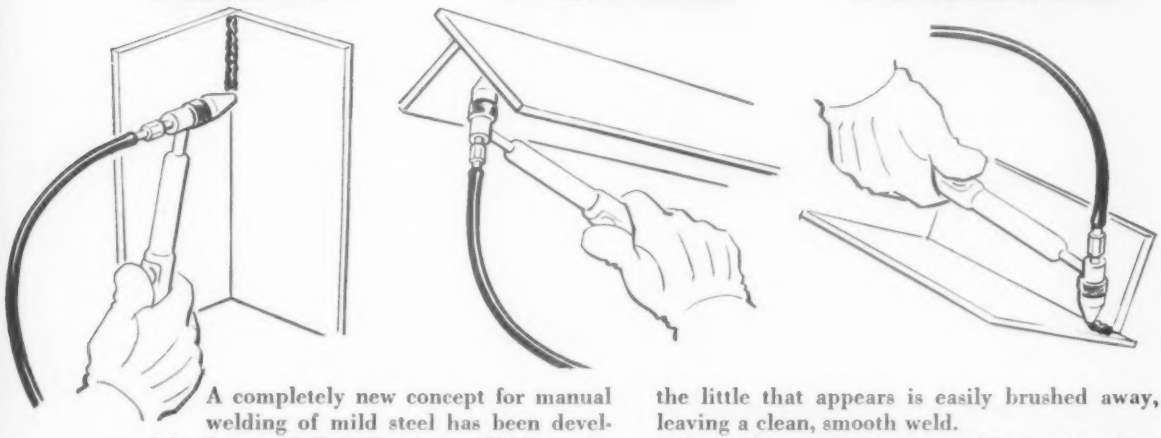
Here, in brief, is how UNIONARC Welding works: A bare steel wire electrode is unreeled through a flexible tube to the torch. Magnetizable flux, conveyed by carbon dioxide under pressure, flows through another tube. At the torch nozzle, the magnetic field produced by the current flowing in the electrode attracts the flux, which coats the wire as it feeds and melts in the arc. In the arc zone, four things take place: (1) The shielding gas and flux stabilize the arc and protect the molten metal from contamination. (2) The molten metal is refined. (3) Desirable weld contour is obtained. (4) The flux blankets and protects the finished weld as it cools.

FOR THE BEST IN ELECTRIC WELDING . . . *LOOK TO LINDE*

modern welding method– Flux Gas Shielded Arc Welding

UNIONARC *is an entirely new method of welding steel in all manual positions...*

VERTICAL **OVERHEAD** **DOWNHAND**



A completely new concept for manual welding of mild steel has been developed by LINDE. Called UNIONARC Welding, the method uses a continuously-fed bare steel wire electrode, which is magnetically coated with flux and shielded by carbon dioxide. The torch can be easily handled in all welding positions—vertical, overhead, downhand. Manual welds can be made at higher speeds and at lower cost than with covered electrodes. UNIONARC Welding produces high-quality welds in steel, even when moderate amounts of rust, scale, and moisture are present.

Among the numerous advantages of UNIONARC Welding are these: Rate of operation is up to three times faster than with covered electrodes. There is no stopping to renew electrodes, since a single loading of wire can be fed smoothly and continuously for periods up to a week. Manual skill needed is no more than that required with covered electrodes. In vertical and overhead positions, the deposition rate in UNIONARC Welding is two to three times greater than with covered electrode methods; in downhand positions, up to twice as great. There is practically no spatter—the little that appears is easily brushed away, leaving a clean, smooth weld.

LINDE has made many notable contributions to welding. Among these are the introduction and development of submerged arc welding (UNIONMELT Welding), non-consumable electrode, inert gas shielded arc welding (HELIARC Welding), and the development of Sigma (shielded inert gas metal arc) welding. LINDE's newest method, UNIONARC Welding, is another *first*—a truly important contribution. Its simplicity and versatility make it unique. Its efficiency and economy have been proved in actual production work. Write *now* for details about UNIONARC Welding, or call the LINDE office nearest you.

LINDE COMPANY, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, N. Y. Offices in other principal cities. *In Canada:* Linde Company, Division of Union Carbide Canada Limited.

The terms "LINDE," "HELIARC," "UNIONMELT," "UNIONARC," and "UNION CARBIDE" are trade marks of Union Carbide Corporation.

Linde
TRADE-MARK

UNION CARBIDE

INTERNATIONAL WELDING NEWS

New West Coast Plant

The recent opening of Weldaloy Products Co.'s new facilities in Burbank, Calif., was announced by J. A. O'Grady, president of that firm.

O'Grady stated that the new plant will serve as headquarters for the newly

created Weldaloy Western Div. This division will be headed and operated by men thoroughly qualified in all phases of resistance welding.

The western division plant, according to O'Grady, was specifically established to serve Weldaloy Products Co.'s customers in the automotive, aircraft, appliance, and the tube and pipe fabrication fields.

The plant housing the Weldaloy Products Co. Western Division facilities is located at 1209 Chestnut St., Burbank, Calif.

Canadian Council of IIW Formed

Membership for Canada in the International Institute of Welding is now held by the Canadian Welding Bureau, Canadian Welding Society and the Department of Mines and Technical Surveys. In order to expedite and direct the activities of the IIW in Canada, these participating members have joined together to form a Canadian Council. This new Council will now direct and conduct the affairs of the Institute and its Commissions in Canada.

The Canadian Council, which acts as a joint instrumentality for the sponsor bodies, had its first meeting on Friday, December 14th, in the offices of the Department of Mines and Technical Surveys in Ottawa.

The purpose of this first meeting was to adopt rules and regulations governing the activities of the Council, to elect officers, to draw up a Budget and to appoint Delegates to represent the Canadian Council at the 1957 Congress of the IIW.

The rules and regulations adopted dealt with the objectives, scope, membership, voting privileges and voting requirements, meetings, duties of the officers, financial responsibilities and selection and responsibilities of Commission Delegates of the Canadian Council. A budget was adopted to cover the remaining portion of the Council's year, i.e., until Sept. 1, 1957. R. A. Dunn of the Canadian Welding Society was appointed Chairman and W. R. Stickney of the Canadian Welding Bureau was appointed Executive Secretary of the Council effective from Jan. 31, 1957 to Aug. 31, 1957. H. Thomasson of Canadian Westinghouse, Mr. Dunn and R. M. Gooderham of the Canadian Welding Bureau were appointed to represent the Canadian Council at the 1957 Congress in Essen, Germany. Other members of the Council are W. P. Campbell and H. J. Nichols of the Department of Mines and Technical Surveys, and E. A. Gill of the Canadian Welding Society.

It is the work of the Canadian Council to serve the interests of its three sponsor bodies—Canadian Welding Society, Canadian Welding Bureau and the Department of Mines and Technical Surveys—and Canadian science and industry in the activities of the International Institute of Welding, and to officially act jointly on their behalf in such activities. The Canadian Council will strive to select official Chairmen, alternates and experts to serve on IIW Commissions, giving due regard to their ability to adequately represent the sponsor Bodies and the Canadian viewpoint on such Commissions. The Chairmen will be responsible for organizing the work of the parallel Canadian Commissions. Through these parallel Canadian Commissions the Canadian Council will strive to publish for its sponsor Bodies and for Canadian Industry the vast wealth of knowledge available through the International Body.

WEAR PROBLEM...
INSIDE OR OUTSIDE.
ONE SOLUTION!
TORCH WELDING
SOLDERING · FILLING · SEALING
TORCH BRAZING
FURNACE BRAZING
ARC WELDING
ALL-STATE
NO. 13 NICKEL SILVER BUILDUP ROD
ALLOYS All-State FLUXES
for welding • brazing • soldering • tinning • cutting
Users Report on Cams: "Using your No. 13 rod to build up such surfaces, we have had 3 to 5 times the cam life."
Users Report on Wrist Pin Holes in 500-lb. Pistons: "No. 13 enabled successful repair where 200 degrees more heat would have spoiled everything. There was no warpage."
For Instruction Book on 62 alloys and fluxes write All-State Welding Alloys Co., Inc. White Plains, N. Y.
ALL-STATE ALLOYS AND FLUXES
REQUEST COMPLETE LIST OF THESE PRODUCTS FOR PROBLEM SOLUTIONS

LATEST INFORMATION ABOUT USS "T-1" STEEL

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It tells WHERE to use USS "T-1" Steel!
WHEN to use it! HOW to use it!

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PERSONNEL

Haile Appointed Linde President

William M. Haile has been appointed president of Linde Co., a division of Union Carbide Corp., it was announced by Morse G. Dial, president of the corporation.

Mr. Haile joined Union Carbide in

William H. Haile

1925 when he went with the Linde Co. in the New Orleans office. He progressed through the Linde sales organization becoming manager of the Eastern Region in 1952 and vice-president of the company in 1955.

Mr. Haile was born in New Roads, La. He received the degree of Bachelor of Science from Tulane University in 1924.

Muller Made Assistant to President

Albert Muller, until recently director of metallurgical research at the Air Reduction Central Research Laboratories, Murray Hill, N. J., has been appointed assistant to the president, Air Reduction Sales Co., a division of Air Reduction Co., Inc.

In his new assignment, Dr. Muller will assist the president of the division, J. H. Humberstone, with respect to the acquisition and the development of new products and processes.

A graduate of Rensselaer Polytechnic Institute, Troy, N. Y., where he received his Ph.D. in 1943, Dr. Muller is a specialist in the fields of ferrous and nonferrous process metallurgy, welding and the development of high energy fuels and oxidants.

Before joining Air Reduction in 1946, Dr. Muller was a research supervisor

Albert Muller

for the National Academy of Sciences War Metallurgy Committee, Washington, D. C.

He is a member of the U. S. Atomic Energy Commission Welding Committee, Ordnance Advisory Committee on Armor Fabrication, and is chairman of the American Ordnance Association Welding Committee. In addition, he belongs to the AMERICAN WELDING SOCIETY, American Institute of Mining and Metallurgical Engineers, the Electrochemical Society, British Institute of Metals and the British Iron and Steel Institute.

Grotevent Promoted by Airco

W. F. Grotevent, formerly plant superintendent of Air Reduction's Riverton, N. J., liquid oxygen plant, has been appointed works manager of the new Chicago liquid plant, it was announced by Dale D. Spoor, AWS, regional vice-president of Air Reduction Sales Co.

Mr. Grotevent joined Airco in 1936 at

W. F. Grotevent

Buffalo, N. Y., and in 1950 became plant superintendent of the Central Falls, R. I., oxygen plant. In 1953 he transferred to the Philadelphia District as assistant regional production manager. He became superintendent of the Riverton plant a year later, and was appointed to his present post in April of this year.

The new air liquefaction plant, scheduled to begin production in June, is being built at a cost of more than $7,500,000 (including related delivery equipment) and is designed to produce 75 tons of high-purity liquid oxygen, nitrogen and argon daily. The plant will serve the area within a 400-mile radius of Chicago.

Mandel and Wade Named

Stephen F. Mandel has been named Director of Market Development and a member of the Policy Committee by All-State Welding Alloys Co., Inc., White Plains, N. Y. His new duties include responsibilities for advertising and other forms of sales promotion.

Stephen F. Mandel

Lee S. Wade

FOR MANUAL APPLICATION

THIS HARD-FACING ROD	FOR THESE CONDITIONS	FOR THIS EQUIPMENT	APPLI-CATION
VICTORTUBE	Severe abrasion	Ripper and ditcher teeth, dredge cutter blades, posthole augers, oil field tools, pug mill knives	ACETY. AC-DC ELEC.
VICTORTUBE BARE-30-DOWN	Severe abrasion	Agricultural tools	ACETY. ONLY
VICTORTUBE "SPECIAL"	Abrasion, severe impact	Oil field bits, rock bits	ACETY. ONLY
VICTOR TUNGSMOOTH	Thin cutting	Augers, bits, blades, screw conveyors, farm tools	ACETY. AC-DC ELEC.
VICTORITE	Earth abrasion, sliding friction	Farm tools, earthmoving rigs	ACETY. AC-DC ELEC.
TUBE VICTORITE	Abrasion, impact	Plow points and farm tools	ACETY. AC-DC ELEC.
VICTORITE 1	Corrosion, heat, abrasion	Chemical and food machinery, arbors, screw conveyors, soaking pit tongs	ACETY. AC-DC ELEC.
VICTORITE 6	Red heat, impact corrosion, abrasion	Forming dies, exhaust valves, cams, steam valves	ACETY. AC-DC ELEC.
VICTORITE 12	Heat, abrasion, impact	Saw blade inserts and other critical applications	ACETY. AC-DC ELEC.
VICTORITE CARBON ARC	High abrasion, thin deposit	Plowshares, lister shares, sweeps	CARB. ARC ACETY.
VICTORALLOY	Abrasion, severe impact	Crushers, dredge pumps and cutters, dipper teeth, tampers, rollers, idlers	ACETY. AC-DC ELEC.
VICTORALLOY #1	High abrasion, medium impact	Bucket lips, rock crushers, muller tires, gyratories	ACETY. AC-DC ELEC.
VICTORALLOY "A"	Angular shock, extreme impact, build-up	Clutch parts, gears, crusher plates, gyratory mantles, build-up for hardfacing	AC-DC ELEC. ONLY
VICTORALLOY "B"	Heavy impact, moderate abrasion	Tractor rollers and sprockets, shovel pads, plates, idlers, etc.	AC-DC ELEC. ONLY
VICTORALLOY "C"	High abrasion, moderate shock and impact	Tractor grousers, pressure rolls, crusher segments, roll crusher teeth	AC-DC ELEC. ONLY
VICTOR MULTI-PASS	Impact, compression, build-up	Drive sprockets and tumblers, rollers, idlers, churn drills, clutch jaws	AC-DC ELEC.

What's proper Victor rod for your hardfacing needs?

THIS CHART GIVES YOU QUICK ANSWER

Use it to select right rods for prolonging operating life of your equipment. You'll be selecting rods that go on quickly and smoothly, thereby saving labor and downtime. Order from your Victor dealer TODAY.

FREE—For more detailed information on how to apply Victor hardfacing alloys to wearing parts, write us NOW for your copy of Victor Hardfacing Manual. It's free.

VICTOR for hardfacing

VICTOR EQUIPMENT COMPANY • *Alloy Rod & Metal Division*

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fitable dealerships open; inquire now!

FOR AUTOMATIC & EMI-AUTOMATIC APPLICATION

THIS TYPE	FOR THESE CONDITIONS	ON THIS KIND OF EQUIPMENT
#0	High abrasion, medium impact	Crusher rolls, rock crushing equipment
VA #1	Abrasion, medium impact	Crushers, scraper blades
VA #2	Abrasion, impact, Multi-pass application	Steel mill applications, tractor idlers
VA #3	Abrasion, light impact	Mill guides, crushers, dredge bushings
VA #4	Multiple layer build-up	Tractor rollers and idlers, sheave wheels
VA #5	Heavy impact, abrasion	Tractor rollers, idlers, mine car wheels, sheave wheels
VA #6	Medium abrasion, high impact	Crane wheels, drums, roll necks
VA #7	Abrasion, high impact	Build-up for hardfacing, mine car wheels
VA #8	Abrasion, high impact	Roll crushers, scraper and grader blades, tool joints
VT #60	Extreme abrasion	Tool joints, grader blades, scraper blades
Mo-Mn	Manganese build-up	Wherever manganese build-up needed

Mr. Mandel received his A.B. from Dartmouth College and his M.B.A. from Leland Stanford University. He was previously New York manager responsible for market development and distribution sales for Fibreglas reinforced plastic products.

Lee S. Wade has been appointed to the position of general sales manager by All-State Welding Alloys Co., Inc., White Plains, N. Y. He relinquishes his duties as All-State regional manager for a large portion of the Midwest, a post he has held since 1955. He has been associated with selling and servicing All-State Alloys and Fluxes throughout his career with the company. Mr. Wade is a member of the AMERICAN WELDING SOCIETY.

I. W. Evans

Evans Promoted by Morgan Engineering

Charles F. Simmers, vice-president—engineering of the Morgan Engineering Co. of Alliance, Ohio, announces the promotion of I. W. Evans, AWS, to the post of chief engineer of cranes. Mr. Evans was formerly chief development and welding engineer at Morgan. He is a graduate from Ohio State University where he received a B.S. degree in welding engineering. Mr. Evans completed his graduate work in metallurgical engineering at Illinois Institute of Technology, where for a year he taught mechanical and metallurgical engineering. He is a member of the Association of Iron and Steel Engineers, the American Society for Metals and is a registered professional engineer in the state of Ohio. He has recently been elected vice-chairman of Stark County Central Section of AWS.

Jacobs Joins Denton and Anderson

Denton and Anderson Co., direct representatives of the Taylor-Winfield Corp., Warren, Ohio, announce the appointment of Robert M. Jacobs as sales engineer in their western New York territory with headquarters in Rochester, N. Y. Mr. Jacobs has been associated with the resistance welding industry for the past three years and has just completed a factory training program at the Taylor-Winfield plant. He holds a B.S. degree from Washington and Jefferson College. Mr. Jacobs is a member of the AMERICAN WELDING SOCIETY.

Robert M. Jacobs

Lutz Appointed by Resisto-Loy

Kenneth V. Lutz, recently of White Plains, N. Y., has been appointed the manager of Resisto-Loy Co., Inc.'s western division, according to a recent announcement from the company's president, W. C. McLott, in Grand Rapids, Mich.

Mr. Lutz, formerly vice-president in charge of sales at All-State Welding Alloys Co., Inc., will direct sales and service to users and distributors thoughout the 11 western states, western Canada, Alaska and Hawaii from his new home in Cupertino, Calif. He is a member of the AMERICAN WELDING SOCIETY.

Kenneth V. Lutz

AT THE FRONTIERS OF PROGRESS YOU'LL FIND

FOR WELDING AND CUTTING...

IN THE RED DRUM

HIGHEST QUALITY

DUST-FREE

AN AIR REDUCTION PRODUCT

NATIONAL CARBIDE

Write for the name and address of the NATIONAL CARBIDE supplier nearest you.

National Carbide Company

General Offices: 150 East 42nd Street, New York 17, N. Y.
A DIVISION OF AIR REDUCTION COMPANY, INCORPORATED

Semi-Automatic Hard-Facing...

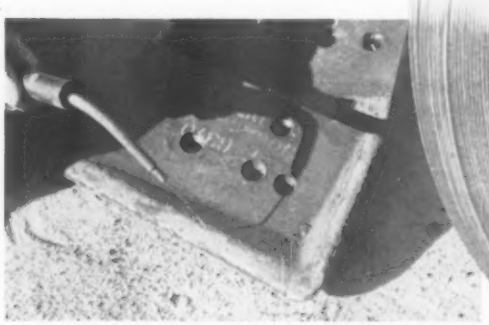
AN ADVANCE IN THE WELDING FIELD

pioneered by STOODY COMPANY

One of the new developments in welding is the series of fabricated tubular alloy wires for application through the semi-automatic welder. Stoody Company pioneered this new process as a means of attaining higher deposition rates and reducing costs. Wire feed is entirely automatic; a motor-driven roll feeds the continuous wire as the arc is struck, continuing until the arc is broken. The operator has only to guide the feed nozzle.

First to supply these alloy wires to the welding industry, Stoody Company now produces the widest available selection of alloys including one containing Borium (tungsten carbides). The range covers alloys for most wear problems involving abrasion and impact. Deposits of these wires closely parallel analyses of similar manual and fully automatic electrodes.

Typical Semi-Automatic Welder *feeding Stoody Wires for semi-automatic Hard-Facing.*



Bulldozer End Bits: *Can be hard-faced in one third of time required by manual process. Stoody 121 is recommended.*

Crusher Rolls: *An ideal application for Stoody 100 because of excellent wear resistance and impact strength. Rolls can be hard-faced much faster with semi-automatic welder.*

The advantages of semi-automatic hard-facing are numerous. Welding speed is 2 to 4 times that of the manual method; there are no stub end losses; savings in welding time and labor costs are enormous; weldor fatigue is reduced. Wires are bare and thus eliminate the need for flux and flux dams; the work is visible at all times during welding. Low penetration reduces dilution of the deposit, assures maximum wear resistance, which is usually superior to that of comparable manual deposits.

Stoody wires, relatively new in the semi-automatic field, are backed by more than 10 years of experience in the production of wires for the fully automatic welder. Your Stoody dealer will be glad to demonstrate the semi-automatic process in your own plant.

STOODY COMPANY

11927 East Slauson Avenue • Whittier, California

NEW LITERATURE

First Section of Welding Handbook, Fourth Edition, Now Available

A little over a year ago it was reported in THE WELDING JOURNAL that the WELDING HANDBOOK was to be divided into five sections and one completely revised section would be published each year.

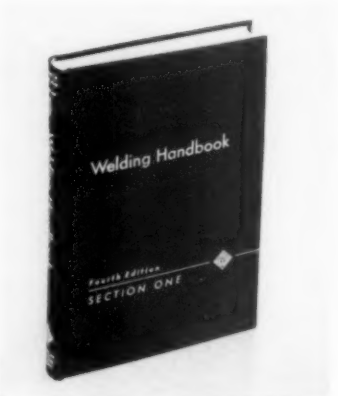
According to a recent announcement by Arthur L. Phillips, HANDBOOK Editor, the first section has been completed. It is being printed now and will soon be available for distribution to eligible members.

Not only is the format new, but the book is modernized. The type is larger, more easily read and is set in one column for convenience and readability. It is written in language suitable for those who will use the HANDBOOK. It is technical without being too technical, and the bibliography at the end of each chapter provides an excellent source of material for further study.

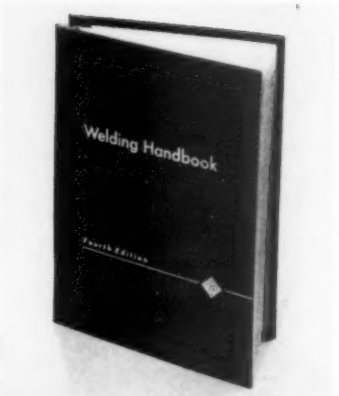
"THE WELDING HANDBOOK," Mr. Phillips points out, "has long been recognized as the most authoritative work available on welding and welding technology. It fills an ever-increasing need. The joining of metals plays such a vital part in the economy and safety of our nation that it can no longer be regarded as merely a tool of industry. It actually represents and is responsible for our way of life today. The importance of a metal or alloy is no longer judged by its monetary value, strength or other properties, but by its weldability. A metal's importance diminishes in direct ratio to its resistance to available joining processes. Progress in metal joining techniques has been so rapid in recent years that it has been impossible for written material to keep pace with developments. Many technical books are out of date by the time they are published and, despite all efforts, it has been impossible to bridge the gap between preparation and publishing, development and printed text.

"This gap, if not eliminated, has been reduced to reasonable proportions by a new concept in handbook publishing. Instead of a 2500-page handbook, which took five years to prepare, a single section has been written—which took one year to prepare. The HANDBOOK has been divided into five sections and one section will be published each year for the next five years. At the end of this five-year period, each section will be revised and a revised section published each year for the next five years.

"The advantages are obvious. Each section will contain up-to-the-minute information because revision will conform to a continuous pattern. The flexibility of this format is such that should a need arise for information on a particular subject it could be covered in the current section instead of having to wait perhaps five years until the next revision."



Additional hard-covered copies of Section One are available



The first section of the Fourth Edition as it will appear in its post binder

The first section contains the basic material needed by everyone associated with welding activities, metal joining or related fields. It is designed to be interpretive. The first volume contains 11 chapters and over 500 pages. Whenever possible, information is reduced to tabular form in order to save space. Much of the material has been taken from company files—material never before published—and the task of gathering the material has been undertaken by hand-picked experts in their respective fields. Only a technical society could obtain such authoritative information from acknowledged leaders, without having to pay a prohibitive price for it. Manufacturers, researchers and practical men have all contributed their quota in order that the welding industry as a whole might profit from their experience and knowledge. Laboratories and testing grounds have made available their findings, making the first section of THE WELDING HANDBOOK as authoritative and as up-to-date as possible.

The tentative arrangement of the sections in the Fourth Edition is as follows:

Section 1: Basic Welding Practices and Fundamentals.
Section 2: Gas, Arc and Resistance Welding Processes.
Section 3: Miscellaneous Metal Joining, Cutting and Maintenance Processes and Practices.
Section 4: Metals.
Section 5: Applications

This system of grouping of subjects has many advantages. All the information concerning a given subject will be available in a single section. It can be removed for study without having to carry the entire HANDBOOK every time the subject has to be studied away from the office.

The first section contains:

CHAPTER 1—Standard Welding Terms and Their Definitions. This is a dictionary of welding terms. To avoid any possible misinterpretation, the descriptive words, terms and phrases commonly used in welding are defined. When these words are used in the book they have one meaning only—the meaning defined in Chapter 1.

Plant, Research Laboratories and World Headquarters

BETTER ORIGINAL FASTER

Low Temperature EUTECTIC WELDING ALLOYS

STRONGER WELDS

EUTECTIC Welding News

PUBLISHED BY EUTECTIC WELDING ALLOYS CORPORATION, 40-40 172 STREET, FLUSHING 58, NEW YORK, N. Y.

XYRON 2-25 REPAIRS RR DIESEL ENGINE SAVES $10,800, WEEKS OF DOWNTIME

A large break in the first cylinder of a 600 horsepower diesel engine almost resulted in the loss of $10,800 by a Midwestern railroad. Attempts to repair the engine with conventional high heat welding materials failed because the block was thoroughly dirt and oil soaked and its tremendous size made pre-heating impossible.

The railroad's maintenance foreman was ready to recommend scrapping the engine when Eutectic's District Engineer suggested welding with patented Xyron 2-25, "Eutectic's" newest and most advanced electrode for all types of grey and alloyed cast iron. Xyron 2-25 is usable fast and cold and is the first non-cracking, porosity free, all position electrode for cast iron.

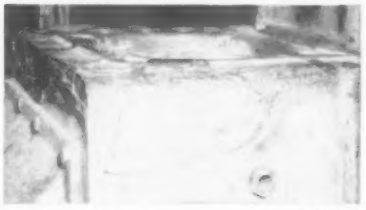
Fig. 1

Repair was begun by veeing out all broken surfaces with Eutec-ChamferTrode, high speed gouging electrode for all metals. (Fig. 1) Gouging with ChamferTrode provided a good surface for deposits of Xyron 2-25 and burnt out many of the impurities in the casting. After the broken parts were reassembled on the engine block, Xyron 2-25 was used to tack weld. (Fig. 2).

Fig.2

Welding machine was set at 100 amps, DC reversed. The weldor then used a stringer technique with short arc to deposit 2" passes of Xyron 2-25. Peening after each pass relieved stress and slag was easily removed.

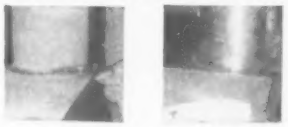
Final results were excellent. Xyron 2-25 produced dense, smooth, porosity free deposits at lowest amperages. (Fig. 3) Fast repair with Xyron 2-25 saved railroad $10,800 replacement cost and avoided weeks of downtime. *(A-71)*



HIGHEST STRENGTH JOINTS WITH EUTECTRODE 201

Welded with patented EutecTrode 2101, the aluminum tine joints on this cement block unloader are up to three times stronger than joints of conventional aluminum electrodes. Loads of close to a ton cause the tines to dip as much as eight inches without cracking. EutecTrode 2101 quickly fabricated the block unloader, produced smooth solid deposits with good color match and high resistance to corrosion. The first aluminum electrode with an extruded flux coating, EutecTrode 2101 does not spatter or fume, produces a quiet arc at lowest amperages. EutecTrode 2101 outperforms all conventional aluminum electrodes. *(A-72)*

EUTECTRODE 680 AC-DC AVERTS 10 WEEK STOPPAGE



A Tennessee stamping plant faced an 8-10 week production stoppage because of a cracked shaft on a 340 ton press. Replacement was estimated at $15,000. But downtime was averted and replacement cost saved by using EutecTrode 680 AC-DC and Eutec-ChamferTrode to repair the shaft at a cost of only $37 in materials. Eutec-ChamferTrode, high speed gouging electrode, was first used to vee out the crack, which extended 6" through the 12" shaft. EutecTrode 680, patented high tensile electrode for very high alloy and carbon steels, was then applied. EutecTrode 680 welds were applied at lowest amperages. *(A-73)*

In answering industry's requests for technical data, Eutectic's research and engineering staffs help industry save thousands of dollars each year. Your questions, like these below, will be answered without obligation by Eutectic's Technical Information Service.

Q. My company's welding manual makes reference to the use of solder in the repair of lamp socket contacts. EutecRod 157 with Eutector Flux 157 was recommended to us for this application. Will you advise? We would like to incorporate this information in our manual for future use. The fact that this soldering is performed by unskilled personnel should be considered.

A. EutecRod 157 is considered an ideal recommendation. Since this alloy has an extremely narrow plastic range, rapid solidification takes place, assuring a good build-up. It is therefore easier to handle by the unskilled. Deposits are harder and have higher electrical conductivity than conventional solders. This means greater resistances to pitting and general wear. Since the alloy has a higher solidus temperature, the possibility of plasticizing the build-up if accidental arcing occurs is virtually eliminated. Contacts also will remain bright and clean since EutecRod 157 does not contain lead or other elements than darken with age. Melting point is approximately 430° F. Electrical conductivity is 18 percent.

Q. What is the electrical resistance of EutecRods 180, 800, and 1804?

A. Electrical resistivity of all three is almost identical in that values of 23/24 microhms per cubic centimeter are obtained on all tests.

Eutectic Welding Alloys Corporation
40-40 172nd Street, Flushing 58, N.Y.

Gentlemen:

I would like further free information on the following:

☐ A-71 ☐ A-72 ☐ A-73

☐ Free 170 page pocket Welding Data Book.

Name _____

Business Address _____

City _____ State _____

"EUTECTIC" WELDING HEADLINES • TIME-MONEY-MACHINERY SAVERS

CHAPTER 2—General Engineering Tables. In each chapter as much material as possible has been reduced to tabular form in order to give the maximum amount of information in the space available. The tables in this chapter are of a more general nature and do not apply specifically to any single chapter.

CHAPTER 3—Fundamentals of Welding Metallurgy. Simply and interestingly told is the story of metals, their alloys, composition, manufacture and structure. This is almost a text in itself on welding metallurgy. It will be found equally useful to the engineer who needs the basic facts and the student who is introduced to the subject for the first time.

CHAPTER 4—Properties of Welded Joints. Impact, fatigue and corrosion resistance are properties which can prevent breakdowns and failures and improve the service life of a part or product. This is important reading for all concerned with design.

CHAPTER 5—Thermal and Mechanical Treatment of Weldments. This chapter covers the thermal treatments in regular use for the improvement of the properties or performance of a welded joint. The controversial subject of peening is discussed and the findings of the Welding Research Council are cited. The safety and efficiency of a weldment are of primary consideration and the thermal treatment selected should be based upon a clear understanding of the service conditions involved.

CHAPTER 6—Design of Welded Joints. The importance of design cannot be overemphasized. Correct joint design can help to control distortion, reduce shrinkage cracking, facilitate good workmanship and produce sound welds economically. This chapter indicates the correct joints to be used with the various welding processes. It explains when they should be used, the type of loading and alternate designs for maximum efficiency. Illustrations show how poor design can restrict production and how a simple change in design can increase both production and efficiency.

CHAPTER 7—Factors and Data Involved in Estimating Costs. Estimating costs correctly is vitally important to all companies, large and small. This chapter shows how certain companies handle this problem. Short cuts are given and a special section is devoted to job shop operations.

CHAPTER 8—Inspection of Welding. The principal methods of inspection currently in use are described. These include: hardness tests, nuclear-energy welding inspection, ultrasonic, proof and destructive testing, radiography, magnetic particle and penetrant inspection, metallographic tests, chemical tests and the various forms of visual inspection. Defects common to welding are illustrated and the cause and effect explained.

CHAPTER 9—Standard Methods for Mechanical Testing of Welds. This information is included to indicate requirements for specimens, testing procedure and the method of obtaining the properties.

CHAPTER 10—Statistical Control of Weld Quality. More and more companies today are relying upon statistical analysis to determine the degree of quality control necessary to obtain a desired result. This chapter explains statistical control in simple language and gives examples of how it is being applied.

CHAPTER 11—Safe Practices in Welding and Cutting. All personnel engaged in industrial activities are concerned with safety measures. The measures cited are for the safety and protection of those engaged in welding and cutting operations. Some are mandatory, but all have been developed to give adequate protection.

The Fourth Edition of THE WELDING HANDBOOK is intended to be the most comprehensive work on welding ever published by the AMERICAN WELDING SOCIETY. The first section reveals the pattern. It indicates how extremely wide will be the coverage of each subject and how exhaustive the technical information.

Copies are now available at a cost of $9.00 per volume from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Safe Practices

The National Safety Council points out that if conditions or practices in hand soldering and brazing are not controlled properly, many hazards may result. These include lead poisoning, burns, dermatitis, fire and irritation from fluxes.

That and more general information is given in recent Council Data Sheet D-445, "Hand Soldering and Brazing," obtainable from the National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Aluminum Bus Conductors

A handbook on the properties and uses of aluminum bus conductors is available from the Aluminum Company of America. Entitled "Alcoa Aluminum Bus Conductor Handbook," the 280-page work presents facts and figures for engineering and maintenance of bus installations. It contains 69 graphs, tables and photographs. Free copies may be obtained by writing on company letterhead to Aluminum Company of America, 793 Alcoa Bldg., Pittsburgh 19, Pa.

Low-Temperature Brazing

Handy & Harman has announced publication of a new bulletin, *Handy News*. This four-page booklet contains illustrated information on various facets of low-temperature brazing. Copies of bulletin No. 76 may be obtained by writing to Handy & Harman, 82 Fulton St., New York 38, N. Y. Copies of Bulletin 23, which describe Handy Alumibraze, are also available from the same source.

Induction Brazing

Bulletin GER-1332, technical article covers advantages of induction brazing, properties, formula for estimating power requirements and necessary tables for computing coupling efficiency for various metals and coil types. Available free from the General Electric Co., Schenectady 5, N. Y.

Standard Metallizing Symbols

With the shortage of technical personnel, time savers are more important than ever. This accounts for the increased use of symbols for standard industrial practices. At the same time, use of standard symbols provides the advantage of more certain interpretation of requirements shown on a drawing than does the use of long, written instructions.

With publication of the Standard Metallizing Symbols, it is now possible to specify metallizing requirements simply yet accurately. These symbols result from the joint efforts of the AMERICAN WELDING SOCIETY Committee on Metallizing and the Canadian Government Specifications Board Committee on Metallizing. Full details are provided for developing metallizing symbols to specify all of the operations—surface preparation, extent of metallizing, thickness of coating and method of finishing. Typical examples are included to illustrate use of the complete symbols.

Copies of the *Standard Metallizing Symbols* may be obtained at $1.00 each from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

with VICKERS* Controlarc* the Versatile DC Welder

Ford Motor Company's Aircraft Engine Division was one of the first to use the Vickers Controlarc DC Welder.

At the time this versatile magnetic-amplifier-rectifier welder was first introduced, Ford had just completed a survey of all the welders on the market. From this study followed recognition of the need for a welder that would provide: better arc stability, retention of arc characteristics under line voltage fluctuations, wider current range and good performance at very low currents, quick speed of response and recovery from arc short, control of volt-ampere curve and easy remote foot control. It was evident that a *true* magnetic amplifier welder would most closely meet the special requirements of their aircraft fabrications.

Today, many companies in the aircraft industry acknowledge the excellent performance characteristics of the Controlarc, and have accepted this fine machine in the fabrication of aircraft, guided missiles and nuclear components.

From exacting aircraft requirements to simple, rugged heavy load air-cutting—the Vickers Controlarc can do a job for *you*.

WRITE TODAY for information.

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VICKERS ELECTRIC DIVISION

VICKERS INCORPORATED a unit of Sperry Rand Corporation

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Air Carbon-Arc Cutting

A 36-page booklet has just been released by the Arcair Co., Lancaster, Ohio and Bremerton, Wash. This is the first complete manual to be written on the Arcair process. It contains sections on operating principles; current requirements; detailed instructions on gouging, cutting, flushing and beveling; special techniques, stainless steel, cast iron, copper alloys, etc.; trouble-shooting chart; operating data; assembly procedure and applications for every industry.

This pocket-size manual is fully illustrated and indexed for easy reference. It is available from the Arcair Co. at 25 cents a copy.

Gas Regulators

A new 40-page catalog covering their complete line of pressure regulators for industrial compressed gases has just been made available by Air Reduction Sales Co.

Entitled "Gas Regulators," Catalog 806 deals with various types of cylinder, manifold and pipe-line regulators, both single- and two-stage, and a variety of specialized equipment such as laboratory and metering regulators and gas proportioners. Flow and pressure charts in graph form give data on the performance of the regulators.

In addition, related equipment—such as station valves, adapters, hose connections and pressure gages—is illustrated and discussed.

A copy of the catalog may be obtained by writing Air Reduction Sales Co., a division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

Semiautomatic process

The Linde Co. announces the availability of the three following booklets on their recently released Unionarc process.

"A Better Way to Weld Steel," Bulletin F-1060, 8 pages. Features comparison of covered electrode welding to "Unionarc" welding.

"New Continuous-Feed Arc Welding," Bulletin F-1076, 4 pages. Development and application of "Unionarc" welding process in industry.

"Unionarc Welding Process," Bulletin F-1066, 8 pages. Technical article describes weld quality obtained from new "Unionarc" welding process.

The three booklets are available free on request from: Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y.

Positioners

Aronson Machine Co. announces that a new bulletin, No. HD57, on gear-driven positioners is now available. This brochure consists of complete descriptions, specifications and optional extras for eight different models of gear-driven welding positioners ranging from 500 to 24,000 lb capacity.

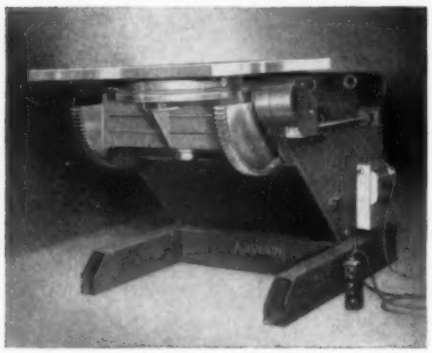
Free copies may be obtained by writing to the manufacturer, Arcade, N. Y.

Tubular Equipment

Copies on two new data folders on tubular equipment are available free from the Tubular Products Division of the Babcock and Wilcox Co., Beaver Falls, Pa. Bulletin TDC-138 contains two tables: one lists dimensional data for 16 sizes of pipe from $\frac{1}{8}$ to 8 in. nominal size for six different weight schedules showing OD, ID, wall thickness and weights per foot and the other table covers ASTM, ASME Specifications, showing title, grade, type and analysis for various carbon, alloy and stainless-steel pipe used for high temperature, high pressure and other services. An 8-page bulletin, known as TDC-185, discusses the seamless titanium metal pipe and tubing produced by the Division. This folder presents in detail the size range and tolerances as well as a complete description of the mechanical, physical and working properties of the metal in tubular form.

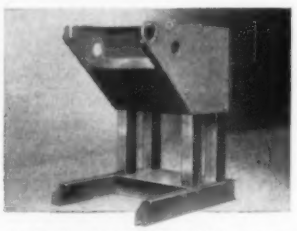
Aronson
HEAVY DUTY GEAR DRIVEN POSITIONERS...
Have BACKBONE

HD Models of ARONSON WELDING POSITIONERS feature the basic BOX TYPE CONSTRUCTION with its advantage of extreme RIGIDITY — Holds your weldments *Steadier* and *Safer* — Affords Protection of Motors and Controls which are mounted *inside* the Box Chassis, out of harm's way — and provides WORKING PLATFORM area on the *flat* steel top.



No Other Type Construction can afford the Rigidity and Strength, and provide the Necessary Backbone for the mechanism that guarantees the user of an ARONSON POSITIONER the Fastest, Highest Precision Welds, and with Complete Safety.

With Table in the Flat Position and with Table Height at Minimum Setting, there is nothing projecting above the top of the chassis to limit the diameter of work you can swing, no column to get in the way, nothing for the weldment to smash into!



4-POST ADJUSTABLE BASE carries out the advantages of the Box Design, affording maximum effective Column of Support many times stronger and more rigid than any single post design.

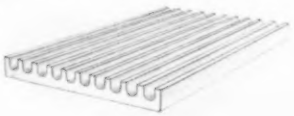
Write for detailed engineering data

another Quality POSITIONER by Aronson MACHINE COMPANY
ARCADE, NEW YORK

More welders use more Sylvania Electrodes

than any other brand

color-coded!



convenient—
protective package

2% Thoriated
1% Thoriated
Puretung*
Zirtung*
*T-M

the only
complete line

ONLY Sylvania has the complete line of tungsten electrodes for shielded arc welding! Whichever gas you're using and whatever type metal you're welding—the four dependable Sylvania electrodes will effectively meet almost any condition you may encounter.

For greater economy, safety, and convenience—Sylvania Tungsten Electrodes are color-coded. You can tell the type of rod merely by glancing at the end. Partially used rods, regardless of length, no longer need to be scrapped for lack of identification. And no longer do you risk ruining a costly job because of choosing the wrong electrode.

Sylvania electrodes are cradled in a protective wood filler and packed ten to the box. Each package carries a color-coded label for easy identification. They're available through leading welding supply distributors only.

SYLVANIA ELECTRIC PRODUCTS INC.
Tungsten and Chemical Division, Towanda, Pa.

TUNGSTEN • MOLYBDENUM • CHEMICALS • PHOSPHORS • SEMICONDUCTORS

SYLVANIA

LIGHTING • RADIO • ELECTRONICS • TELEVISION • ATOMIC ENERGY

Welding Torches

Three Oxweld welding blowpipes are described in a new six-page folder made available by Linde Co. According to the manufacturer, operation on low-pressure acetylene is the unique feature of all three blowpipes. Low-pressure operation makes it possible to operate these blowpipes at acetylene pressures less than 1 psi, which is far below the pressure requirements of ordinary blowpipes. Attachments that quickly convert these blowpipes from welding to flame-cutting operations on all thicknesses of metal up to 8 in. are also described. Complete information and performance data on welding heads and cutting nozzles is also included.

Copies of this new folder may be obtained by writing to Linde Co., 30 E. 42nd St., New York 17, N. Y. Ask for Form 1007.

Automatic Welding Equipment

Bulletin GEC-1334B includes application information, product features, specifications and illustrations of General Electric's Fillerare automatic welding equipment for consumable-electrode gas-shielded welding. Available from the General Electric Co., Schenectady 5, N. Y.

Motor-Generator Welders

Bulletin GEC-1453 includes detailed product descriptions, specifications, performance curves and other pertinent data on the General Electric Co.'s recently announced 300- and 400-amp motor-generator welders. Available from the General Electric Co., Schenectady 5, N. Y.

Grinding Wheels

The revised American Standard Safety Code for "The Use, Care and Protection of Abrasive Wheels, B7.1-1956" has received outstanding acceptance in the metalworking industry. The Grinding Wheel Institute reports that the initial printing of 87,000 copies is completely exhausted, necessitating an immediate reprinting.

Copies of the revised Code may be obtained free of charge by writing the Grinding Wheel Institute, 2130 Keith Building, Cleveland 15, Ohio, on your company letterhead.

Resistance Welding

The new 24-page laboratory bulletin SP-18, of the Taylor-Winfield Corp., Warren, Ohio, illustrates resistance weld production developed by T-W's research laboratory. Included are photos and descriptions of more than 300 different products mass produced by resistance welding. The new bulletin covers spot, projection, flash-butt, upset-butt and seam welding, electro forging and special applications in nonferrous metals, stainless steel and aluminum and small parts.

For your copy, write to the manufacturer at the above address.

BRAZING MATERIAL COSTS CUT 24% to 38%

NEW PHOS-SILVER-6M developed by Westinghouse SAVES $1.00 OR MORE PER POUND!

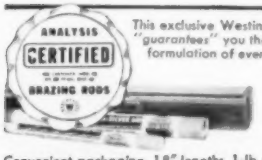
There is now a brazing alloy *proving* itself *superior* to brazing materials costing *3 to 4 times as much!*

It is the new Phos-Silver-6M—made by *extrusion* methods!—*blanketed* under *inert gas!* This eliminates the oxides that cause most brazing troubles. And produces *new versatility* in a brazing rod, with *exceptional* flow characteristics, *remarkable* ductility, and *unsurpassed* appearance of the finished work!

Moreover, Phos-Silver-6M (as *all* the new Westinghouse alloys), has been proved throughout stringent laboratory and shop tests, toughest production runs! Then, is now ANALYSIS CERTIFIED!—*assuring you* the *same consistent, best possible* brazing results!

Order *trial* packages *now!* You'll *standardize* on Westinghouse Brazing Materials *tomorrow!* J-22082-A

YOU CAN BE SURE...IF IT'S Westinghouse



This exclusive Westinghouse Seal "guarantees" you the correct formulation of every rod!

Convenient packaging, 18" lengths, 1-lb and 5-lb tubes. Standard 25-lb package, 36" lengths.

Select from the Westinghouse MOST COMPLETE LINE OF BRAZING MATERIALS IN THE INDUSTRY!

Phos-Copper®, Phos-Silver #2, Phos-Silver*, Phos-Silver-6M, Phos-Silver-15. These round, extruded rods give approximately 20% more feet per pound than square rods of the same diameter! (Same alloys also available in rod form, wire in coils, or rings.)

POWER-UP with Westinghouse advanced brazing materials!

*Trade-Mark

REVIEWS

OF NEW BOOKS

German Engineer's Handbook

Hütte, Bandi, Fertigung. Volume 1, Production. Fifth Edition, 1957. 966 pages, 5¾ x 8¼ in. Cloth cover; price (69.50 marks), approximately $17. Published by Wilhelm Ernst and Sohn, Berlin-Wilmersporf, Germany.

This volume of the renowned German handbook deals first with the properties and testing of materials, then with production processes and finally with the machinery involved in these processes. Nearly eighty engineers contributed sections to the handbook.

Welding, gas cutting and soldering are treated in the chapter on the shaping of metals, and also in the chapter on apparatus for shaping metals. The former section (36 pages) contains a great deal of useful information on all cutting and welding processes and lists all German standards concerned with each process. The latter section (13 pages) describes equipment for gas, arc and resistance welding.

A GENERAL ELECTRIC FIRST . . .

All-Position Welding On Mild Steel with Fillerarc* Equipment

NOW...GET FAST, ALL-POSITION WELDING USING CO_2 WITH EXCLUSIVE G-E FILLERARC GAS-SHIELDED PROCESS

At last, you can weld mild steel with low-cost CO_2 *without spatter and still get deep penetration.* General Electric's Fillerarc equipment makes this possible.

Compared with stick electrode welding, Fillerarc consumable-electrode, gas-shielded welding is twice as fast, eliminates spatter, and needs no extra-close fitup. Fillerarc equipment is available for both automatic and semiautomatic welding.

Here are some more important reasons why you can now weld in any position faster and better with Fillerarc equipment:

WELD WITH SMALL WIRE. Fillerarc wire drive *pulls* wire as small as .035 inches into the easy-to-use gun. This size wire tends to kink with push-type apparatus.

SPECIAL REACTOR permits five welding ranges for greater adaptability in all applications . . . plus better quality welds—without spatter.

FILLERARC GENERATOR with rising volt-amp characteristic holds a constant arc length, regardless of changes in current.

For more information about General Electric's semiautomatic Fillerarc welding process, contact your nearby G-E Welding Distributor or Welding Department Sales Office . . . listed in the yellow pages of your telephone book. Or write for bulletin GEC-989, General Electric Co., Schenectady 5, New York. 713-11

EXCLUSIVE FILLERARC WELDING technique is easy to learn. Even your new operators can begin making satisfactory welds in any position in less than ten minutes.

EFFECTIVE ALL-POSITION WELDING with Fillerarc process using CO_2 on mild steel was proved by demonstration at recent AWS Show. Ask for your demonstration today.

*Reg. trade-mark of General Electric Co.

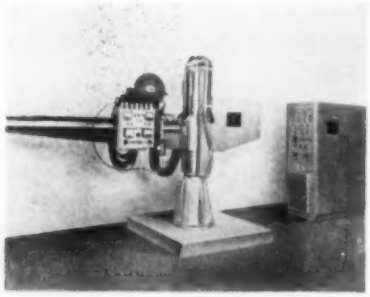
Progress Is Our Most Important Product

GENERAL ELECTRIC

NEW PRODUCTS

Welding Head Manipulator

Air Reduction Sales Co. has recently introduced a new welding-head manipulator and control console for longitudinal and circumferential welding. The unit was engineered by Airco's



Machine Welding Department for the purpose of universal positioning of a welding head and accurate variable speed traverse of the head.

The manipulator, of all-welded construction, is especially designed for precision welding applications on aircraft jet engine components and similar intricate parts.

Both gas-shielded, tungsten-arc welding and gas-shielded metal-arc welding automatic heads may be mounted on the manipulator.

The electrical console provides all the necessary controls for complete programming of the welding operation. Electronic timers are provided for sequence control.

Detailed information may be obtained by writing Machine Welding Department, Air Reduction Sales Co., a division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

Fibre Glass Face Shield

Claimed to be the first with a fibreglass spark guard is a new face shield developed by Sellstrom Mfg. Co., Palatine, Ill. The manufacturer says use of this material eliminates the moisture and heat absorbing characteristics that quickly distort or destroy ordinary face shields used in welding, grinding and other hazardous occupations.

Besides its shape retaining qualities, the new face shield is said by the manufacturer to afford a larger window area than similar protectors; coverage around the face is 19 in., with a choice of either 8- or 10-in. window height. An easy operating ratchet adjustment provides the plastic headgear with a com-

fortable but exact fit to the head of the wearer. Windows, available in green or clear shades, are easily replaced; they are also supplied with an aluminum binding if desired.

Further information on the new Sellstrom No. 328 Face Shield may be obtained by contacting the manufacturer. Address Sellstrom Mfg. Co., Palatine, Ill.

"Water Mizer"

Van Vooren Products, 2133 9th St., East Moline, Ill., announce that a new model "Water Mizer" has just been put into production.

Some features of the new model are: Three Hi-Lo monitor outlet ports—pilot monitor flow from each port can be of different volume. This is ad-

justed by a needle valve in each water circuit.

Water at line pressure will flow from all ports when a weld is made or a thermostat calls for water.

Pilot lights are on when valves are open, and a toggle switch on the panel controls power supply to the unit.

For more complete details, write directly to the manufacturer at the above address.

D-C Welder

Miller Electric Manufacturing Co. of Appleton, Wis., have just released information covering their newest rectifier type d-c welder. Featuring new transformer, new weld stabilized circuit and new completely sealed semimetallic rectifier, it's claimed the "Gold Star SR" delivers maximum arc stability for

greater metal deposition with all electrodes in all positions. Claim is also made that this machine has "a higher short-circuiting current which makes it possible to 'pinch the arc' in vertical and overhead welding."

Effective immediately, all Miller SR series welders will be available only in the new Gold Star machines. Complete particulars on the Gold Star SR will be sent upon request to Miller Electric Manufacturing Co., Inc., Appleton, Wis.

Brazing Alloys

Special vacuum-tube grade silver and gold brazing alloys are available in production quantities from Handy & Harman. According to the manufacturer, these alloys are designed specifically for brazing electronic components in which the concentrations of metallic impurities must be kept to an absolute minimum.

These alloys are carbon-free and meet all applicable industry specifications on maximum content of cadmium, zinc and other volatile elements not allowable for vacuum-tube work. They are supplied in wire, strip and sheet form in all the usual gages.

Further information about the vacuum-tube grade brazing alloys can be obtained from the manufacturer, Handy & Harman, 82 Fulton St., New York 38, N. Y.

METAL & THERMIT CORPORATION
GENERAL OFFICES: RAHWAY, NEW JERSEY
MUREX® Electrodes Mild Steel, Low Alloy,
Stainless, Aluminum Bronze, Cast Iron, Aluminum
also HARDEX—new low hydrogen, hard surfacing electrodes
WELDING MACHINES
AUTOMATIC — constant voltage, for semi- and full-automatic welding
MANUAL — light or heavy duty, portable or stationary
ACCESSORIES Holders, helmets, gloves, cable, etc.
fine quality, prompt service— local rep's phon
A B C D E F G H I J K L M N O P S T U V

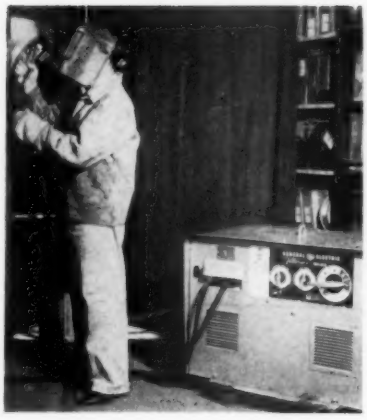
Bifocal Accessory

An aid for welders who wear bifocal glasses is a new optical accessory for welding helmet windows developed by the Sellstrom Mfg. Co., Palatine, Ill. The "Sellstrom Magna-Weld Plate," designed for use with personal glasses, fits behind the regular helmet filter lens

where it is said to provide magnification for near vision throughout the entire "window" area.

Any standard welding helmet can accommodate the Sellstrom "Magna-Weld," according to the manufacturer. Made of precision ground and polished ophthalmic glass and securely mounted in a rugged frame, it will restore to the bifocal wearer the use of the large upper portion of his glasses.

Additional information and copies of Bulletin 33-B can be obtained by writing direct to Sellstrom Mfg. Co., Palatine, Ill.



Welding Power Sources

Two new power sources, designed specifically for consumable-electrode gas-shielded welding, have been announced by the General Electric Co.'s Welding Department.

Both the constant-arc length and the constant-voltage motor generators are rated 450 amp, 60 cycles.

Two-high stacking of the new units makes possible considerable savings in floor space, according to company engineers. Other features of both units are: redesigned fan and baffled air ducts for reduced noise levels; complete phase insulation of motor stators for increased life; oversized sealed bearings; and constant pressure brushes, for correct settings.

The special reactor for control of current peaks when welding with carbon dioxide and mild steel is available as optional equipment on the constant-voltage unit.

For more complete details, write directly to General Electric Co., Welding Department, Schenectady 5, N. Y.

Safety Glasses

Ultra-modern lens styling features the new plastic frame safety glasses announced by Chicago Eye Shield Co.

According to manufacturer, frames are rigid and will retain their original shape without bowing. Nose pads are

broad-bearing and give most comfortable distribution of weight. A choice of two colors is offered—opaque slate (bluish gray) to eliminate light reflection, or translucent flesh.

The new glasses are available in three sizes—No. 375 44 x 37 mm; No. 376 46 x 39 mm and No. 377 48 x 41 mm.

High-Temperature Solders

Two new high-temperature soldering materials have been announced by Aluminum Company of America. The new products are Alcoa Solder No. 805 and Alcoa Soldering Flux No. 66.

A high-zinc solder (95% zinc, 5% aluminum), the new product has been successful in joining heat exchanger return bends, electrical connections and other similar applications. According to the manufacturer, it will join all aluminum alloys, and make joints between aluminum and other metals such as copper, brass, steel, stainless steel, nickel, etc. It has a melting range of 715 to 725° F.

Alcoa Soldering Flux No. 66, recommended for use with the new solder, can be applied dry, or as a 70% flux-30% normal propyl alcohol solution.

Additional information concerning the new products can be obtained at the nearest Alcoa sales office, or by writing Aluminum Company of America, 795 Alcoa Building, Pittsburgh 19, Pa.

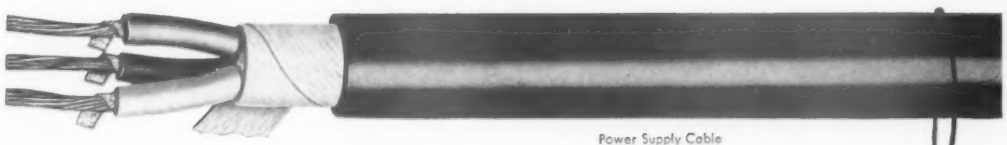
Foundry Saves 12½ Hours With Arcair

Vancouver Iron Works, in British Columbia, uses the Arcair Process for removing excess metal from reaction-type turbine castings —"used to take 14 hours to remove the 2¾" thick, 6" high, 16" long metal. Arcair does it in 1½ hours and no cleanup is needed." Savings on over-all preparation cost — 65%. This is typical of many jobs throughout industry where the Arcair process saves both time and costs. The process consists of a torch, a special type of electrode, ordinary shop air and an ordinary D.C. welding machine.

Arcair COMPANY
P. O. BOX 431, LANCASTER, OHIO
P. O. BOX 4227, BREMERTON, WASH.

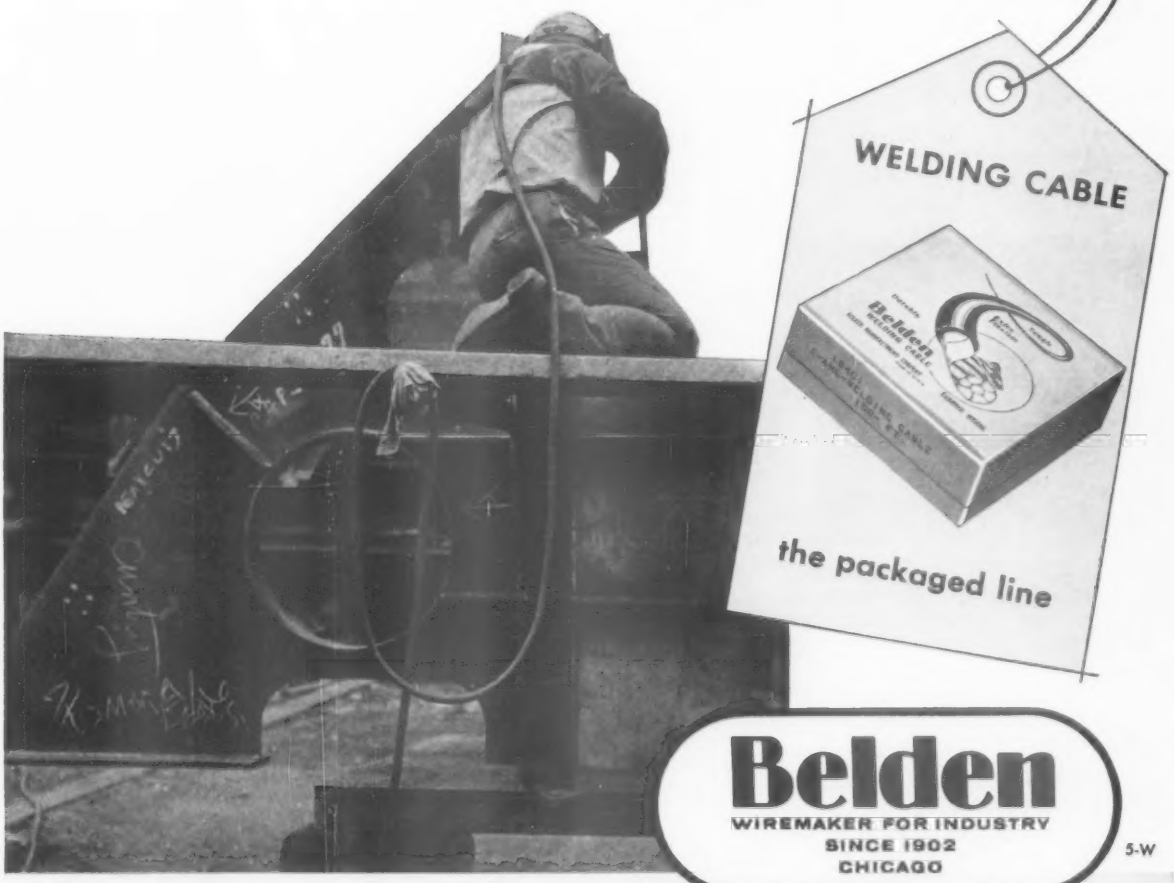
To help you cut costs over chipping and grinding, ask your Arcair dealer for an on-the-job demonstration, or write today for the case history booklet.

If it's worth engineers' time...



Power Supply Cable

...it's worth engineered cable



Belden
WIREMAKER FOR INDUSTRY
SINCE 1902
CHICAGO

5-W

Magnet Wire • Lead and Fixture Wire • Power Supply Cords, Cord Sets and Portable Cord • Aircraft Wires
Welding Cable • Electrical Household Cords • Electronic Wires • Automotive Wire and Cable

Inert-Gas Holders

Air Reduction announces their new line of manual and machine Heliweld holders. Heliwelding is Airco's inert-gas tungsten-arc welding process.

According to the manufacturer, light-weight air-cooled and water-cooled

manual holders, a heavy-duty water-cooled manual holder and three new water-cooled machine holders for automatic and semiautomatic Heliwelding are now available.

More information about these holders may be obtained by writing Air Reduction Sales Co., Inc., 150 E. 42nd St., New York 17, N. Y.

Iron, Powder Electrode

The availability of an all-position, E-6013 iron, powder type electrode has been announced by the A. O. Smith Corp. The electrode has been desig-

nated as SW-15 I. P. It is described as being the first all-position iron-powder electrode.

For complete details, write to the company, c/o Box 584, Milwaukee 1, Wis.

Tip Cleaner

A new tip cleaner has been manufactured by Easy Tip, Columbia, Mo. The tip cleaners, $2^3/_4$ in. long, are soldered onto a metal top and, according to the manufacturer, can be clamped into chucks for special drilling jobs. A set of twelve is packed in a plastic container. For further information write Easy Tip, Box 689, Columbia, Mo.

Pallet Lifter

The Cady Metal Fabricating Co. announces a new series of pallet lifters designed to handle cartoned electrodes with hoists or cranes, thus eliminating

the unloading of cartons individually by hand.

Standard models from one ton capacity and custom models are available to meet specifications. Complete information is obtainable by writing to Cady Metal Fabrication Co., North Tonawanda, N. Y.

Work Table for Induction Heating

New self-contained, two-station work table designed with complete flexibility to perform hardening, brazing, annealing and soft soldering operations has been introduced by Welduction Corp., 10230 Capital Ave., Detroit 37, Mich. Standard units are equipped with 220/440, 3-phase motor generators available in ratings from $7^1/_2$ to 30 kw. The work table has an output of 220 v, 10 kc, single-phase. Unit comes fully equipped

for immediate installation.

According to the manufacturer, work table comes completely equipped with volt, amp, kva and kw meters. All meters are rated in percents. Lights indicate "heat on" and "generator on."

IMPORTANT!

Author's abstracts for 1958 AWS National Spring Meeting must reach AWS headquarters not later than August 15, 1957.

Also included is an open-sight drain for visual check of cooling waters for generator, capacitors, transformers and work coils.

Additional information may be had by writing directly to the manufacturer at the above address.

Attachable Type Welding Plugs

Joy Manufacturing Co. announces completion of a set of connectors (mating male and female plugs) for use in welding cable leads and welding whips. The manufacturer states that

these units are supplied in one size only and have a maximum welding service rating of 550 amp. They can be attached to all cable sizes from No. 4 through No. 4/0. For further details, write to Joy Manufacturing Co., Electrical Products Division, 1201 Macklind Ave., St. Louis 10, Mo., and request free bulletin No. SM-4.

Portable X-Ray Gear

Machinery and Welder Corp., 1324 W. Fulton St., Chicago 7, Ill., announces their latest manufactured item, a portable running gear for the Fedrex Port-

able X-ray equipment. The latter is manufactured by Carl Drenck Electro Technical Laboratories of Copenhagen and is nationally distributed by the Chicago concern.

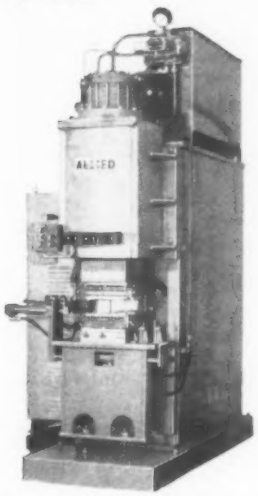
For further details, write to Machinery and Welder Corp. at the above address.

Since you're looking for better tools . . .

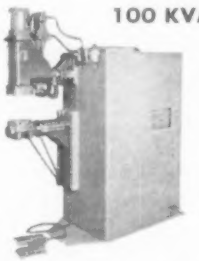
. . . LET'S TALK STANDARD WELDERS!

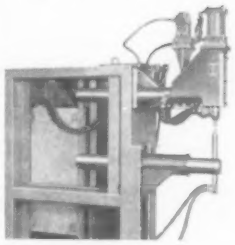
Allied's new roller head press type combination spot and projection welder (lower illustrations) has 8 outstanding advantages. Standard models are approximately one foot less in width than conventional welders, accomplished by placing arms off-center with controls installed within chassis frame where protected. Arms can be installed left or right of center making possible convenient welding of irregular-shaped pieces that fit naturally around corner of machine. Machines with right and left hand mounted arms may be installed adjacent to each other and within 9½" for sequence welding. Arms may be extended by simply loosening 3 screws on casting to give up to 30" throat depth. Vertical adjustment of lower arm up to 15" is provided without changing current characteristics except on air gap since transformer is connected directly to arm support casting instead of mounting plate. By removing 4 bolts, head may be replaced with special adaptations such as multiple guns or projection welding platens. This is done in minutes on the job. Welders are completely water cooled with open or closed circuits. Available in standard sizes: 30, 50 and 75 KVA with 1000 P.S.I. at 80 lbs. line pressure and 75, 100 and 150 KVA with 2300 P.S.I. at 80 lbs. line pressure and on up to 750 KVA in press welders (top). Prices are well below that of conventional welders of equal capacity.

750 KVA



100 KVA

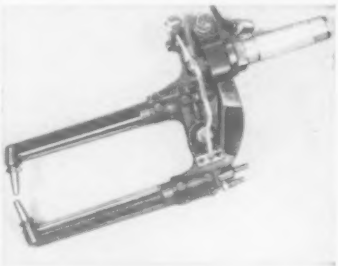


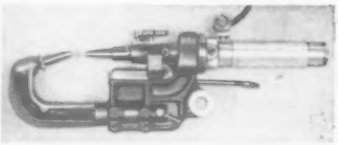


Write for information.

. . . LET'S TALK WELDING GUNS!

Operation so cool you can hold your hand on the jaw extension right below the point is main feature of this new line of portable guns. Incoming water reaches point through tube insulated almost its entire length from metal of jaw by return water jacket which has 5 times capacity of in-flow tube. Heat transfer to the in-flow tube is much less than with small diameter cast-in return water tubes that build up excessive heat in the jaw extension. Use contact fulcrum pin in place of conventional shunt which tends to overheat causing early failure Built-in guide for moving jaw prevents wear on fulcrum pin if gun is used in cocked position. Line includes "C" and scissors type with upper or lower jaw operating and types for special applications. Guns have been on heavy duty production test for 2 years.





YOUR SPECIAL EQUIPMENT PROBLEM — *HOW BIG IS IT . . . REALLY?*

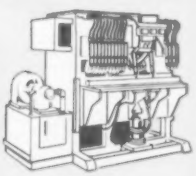
If it involves special equipment for a production welding operation it may not be a problem at all—just an assignment when placed in competent hands.

This is our kind of work—we specialize in it—do it every day; designing and building special machines for welding everything from bathtubs to trailers, frequently including provisions for automatic handling and transfer where the job is a part of a production line set-up.

We're no brain trust here at Allied Welder, but we keep some awfully important production people happy with our creative designing and manufacturing know-how—delivery, too.

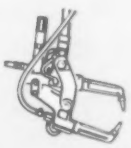
May we work with you on your next job?

Standard Welders



Special Welders

Automation Equipment



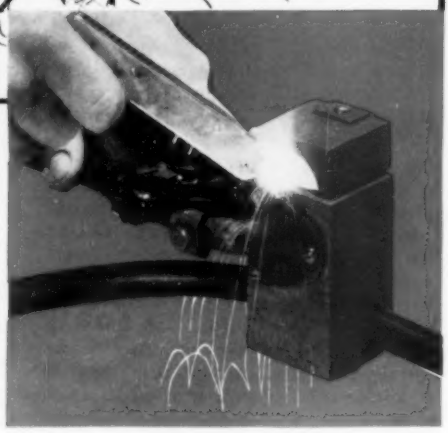
Automatic Arc Welders

Welding Guns

ALLIED WELDER CORPORATION

8700 BRANDT DEARBORN, MICHIGAN

Creative Design



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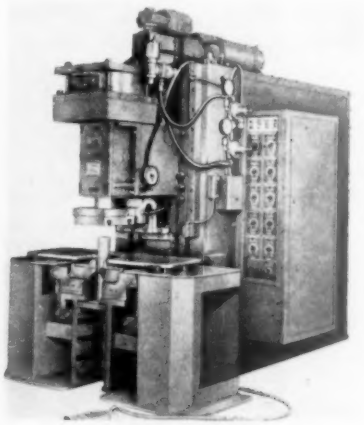
1350 Castlefield Ave., Toronto, Ontario

Spot and Projection Welder

Sciaky Bros., Inc., 4914 W. 67th St., Chicago, Ill., announce the design of a spot and projection welder, the PMCO, 6T, which is the press type, air-operated and three-phase.

The manufacturer states that this welder has proved itself well in fabrica-



ting critical piece part assemblies for farm implements at Massey-Harris Ferguson Ltd., Toronto, Ont., Canada. Sciaky claims that short production runs are practical because setup time is small for the different operations. To learn more about this machine, write to the Chicago address,c/o Department M-17, and request "Resistance Welding at Work," Vol. 5, No. 1.

Welding Positioner

The Positioning Equipment Division of Worthington Corp., Harrison, N. J., has recently announced the development of its new Model 10P Welding Positioner

for automatic welding requiring close speed regulation.

The Model 10P has a load capacity of 1000 lb at 4-in. eccentricity and 4-in. center of gravity. The round table has a diameter of 29 in. with 4 radial T slots.

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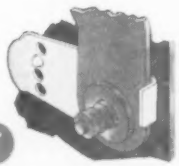
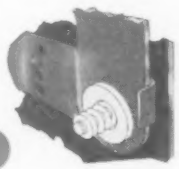


Positions helmet for overhead and vertical welding. Positive stop, easily adjustable to any of 4 positions without tools. Allows normal raising of helmet on friction joints.

LONG-LASTING FRICTION JOINTS 6



A variety of designs for all purposes, allowing easy, outside adjustment with no plastic parts to break. A slight nod brings Helmet to operating position.

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The supreme comfort of Genuine Leather (also in Simulated Leather). Smooth overlap construction, no annoying wrinkles, felt padded.

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The positioner has been designed for extremely accurate handling of lightweight weldments for all manual and automatic welding operations. It has a height adjustment of from 27 to 42 in., available by means of manual or motor operated elevation.

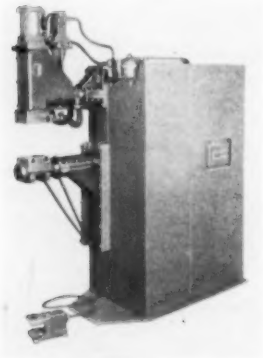
For complete details, write directly to manufacturer at above address.

Resistance Welder

Eight outstanding advantage-features are claimed for a new roller-head press-type combination spot and projection welder now in production at Allied Welder Corp., 8700 Brandt, Dearborn, Mich.

According to the manufacturer, the new welder saves floor space, standard models being approximately one foot less in width than conventional welders. This is accomplished by placing the arms off center with the controls installed next to the arms and within the welded chassis frame where they are protected.

The head on the upper arm is demountable. By removing four bolts the standard head may be replaced with special adaptations such as



multiple welding guns or projection welding platens. This can be done in minutes on the job.

Allied's new welders are completely water cooled with open or closed circuits and one of their outstanding advantages is cooler operation. They are available in two standard sizes: 30, 50 and 75 kva with 1000 psi at 80-lb line pressure and 75, 100 and 150 kva with 2300 psi at 80-lb line pressure.

For more complete details, write directly to Allied Welder at above address.

Soldering Flux

Although soldering is usually done in the range of 360–500° F, it is frequently necessary in certain types of work to use alloys with melting points ranging down to 150° F. For just such applications an entirely new type of soldering paste has recently been developed by American Solder & Flux Co., 19th & Willard Sts., Philadelphia 40, Pa. This new flux, called Amco No. 261, is entirely free of chlorides and rosin compounds. According to manufacturer, it is active at very low temperatures and has a long life. Thus, when used with conventional solders, the cleaning action will begin about 150° F and continue right up to the melting point of the regular solder.

Write to American Solder & Flux Co. 19th & Willard Sts., Philadelphia 40, Pa., for complete details.

Prescription Flash Goggles

The availability of the first flash goggles with prescription lenses is announced by Air Reduction Sales Co.

The goggles are for wear under the welding helmet or hand shield in inert-gas-shielded metal-arc welding, as recommended in the safety standards of the AMERICAN WELDING SOCIETY.

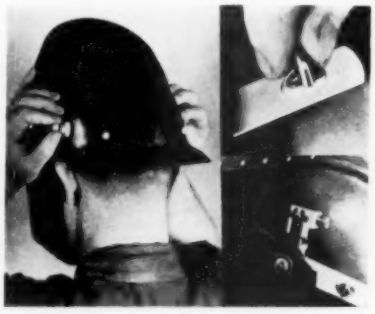
They are obtainable in ten lens styles; variations of the single-vision, bifocal and trifocal types. As specified in the safety standards, they have side shields and the lens shade is No. 2.

For prescription forms and complete information refer to the local authorized Airco dealer or write Air Reduction Sales Co., a division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

Safety Welding Helmet

According to the Kedman Co., the new Huntsman "Roto Clip" helmet linkage permits a practical, fast, easy method of attaching or detaching the welding helmet without removing the hard cap from the head. Therefore, it provides head protection for the welder 100% of the time.

This new combination also has "Adjusto-Vision," another brand new development permitting perfect individual vertical adjustment of the welding plate



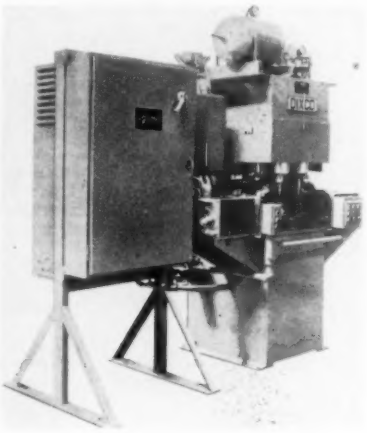
retaining frame before the welder's eyes for his own comfort.

Bullard hard caps come in a variety of colors.

For additional details, write directly to Kedman Co., 233 S. 5th West, Salt Lake City 1, Utah.

Stud Welder

A new automated four-stud projection welder is pictured which improves efficiency and reduces the costs of manufacturing automatic transmission components. It was designed and built by



Dix Engineering Co., Inc. (Detroit), Lincoln Park, Mich. The new machine is custom made for a leading manufacturer of automobiles.

According to the manufacturer, a unique feature of the precision welder's performance is its ability to hold the close tolerances required.

For additional information, write to the manufacturer at the above address.

Hard-Surfacing Paste

A hard-surfacing paste, known as Hi-C 60, has been developed by Western Carbide Corp., 6840 Vineland Ave., North Hollywood, Calif.

According to the manufacturer, the paste creates a deposit of high hardness that enables metal surfaces to withstand extreme conditions of abrasion or high temperature. Hi-C 60 can be applied to any metal with a melting point higher than the paste, 1850° F. The paste itself, a permanent suspension of powdered hard-surfacing alloy in a water base solution, can be applied by spatula, brush or by extrusion from a tube. Hardness ranges from 55 to 61 on the Rockwell C scale.

For more details, write the manufacturer at the above address.

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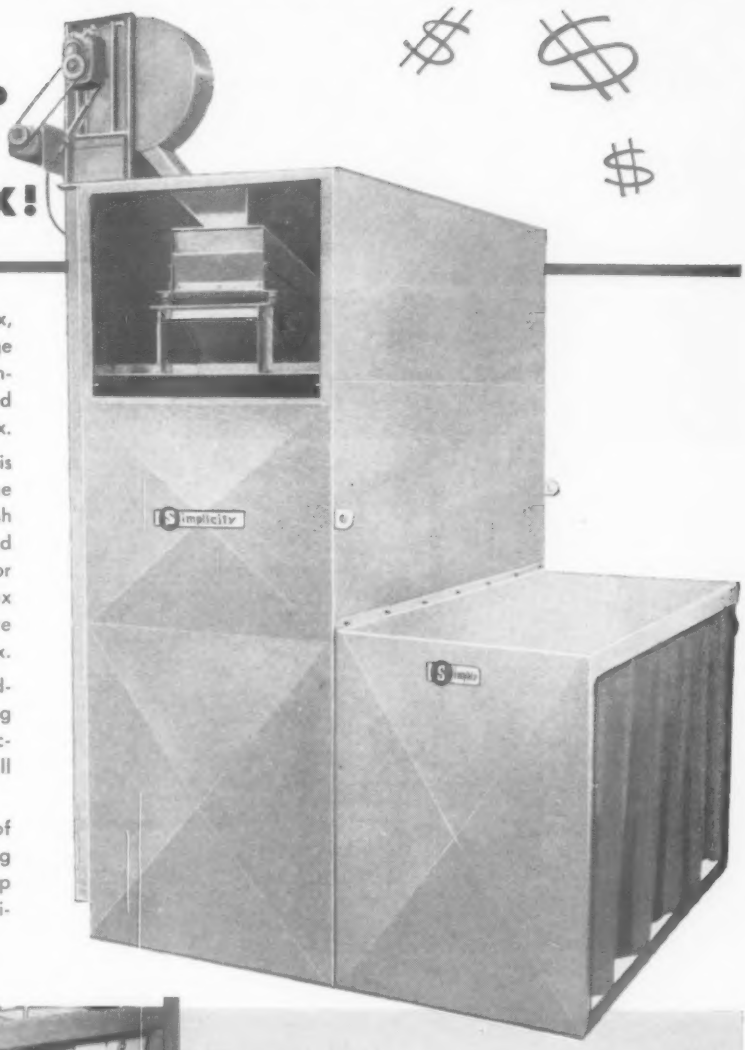
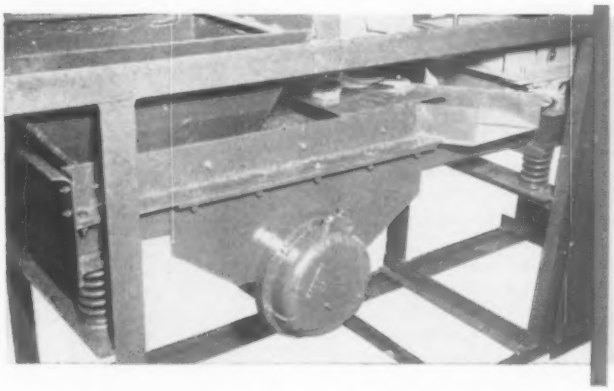


When you discard spilled and fused flux, you're throwing profits to the wind. A large automotive plant solved this problem by installing the Simplicity Flux Reclaim Unit, and saving $5,000 a month salvaging used flux.

Sound good? It should, if your plant is equipped with submerged arc welders. The Simplicity Flux Reclaimer is designed to crush used flux, remove metal particles, dust and fines, and give you refined flux ready for re-use. Mixed in proper ratio with new flux (depending upon type of work) welds are obtained equal to those made with new flux.

Equipped with a two surface vibrating feeder, bucket elevator, double deck vibrating screen, 15" x 9" crusher and two magnetic-pulleys, the Simplicity Flux Reclaimer will more than pay its own way.

Complete installation drawings and prices of these SIMPLICITY units may be had by writing directly to the factory . . . a logical first step in determining ALL the money-saving possibilities these machines may hold for you.



View of 12" x 4'9" two surface oscillating feeder, showing side discharge for removing scrap, metal particles and other foreign objects.

195

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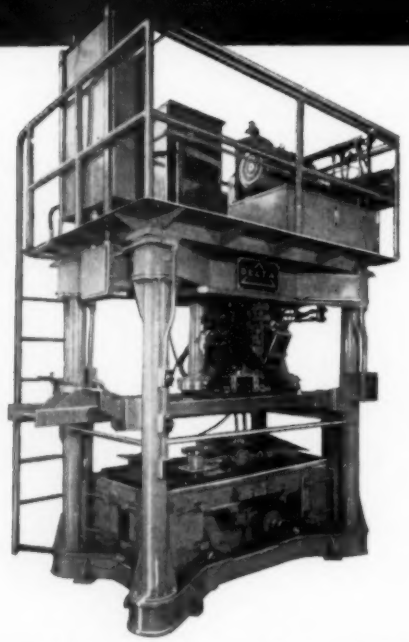

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Welding Research

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W. SPRARAGEN, DIRECTOR

SUPPLEMENT TO THE WELDING JOURNAL, JULY, 1957

EFFECTS OF INTERSTITIAL ELEMENTS ON WELDABILITY OF TI-7% AL-3% MO AND TI-6% AL-4% V

A continuation of the study of the effects of the interstitial elements carbon, nitrogen, oxygen and hydrogen on the weldability, or as-welded ductility, of titanium and its alloys is reported upon by the authors

BY JOHN F. RUDY, JOSEPH B. McANDREW AND HARRY SCHWARTZBART

ABSTRACT. This paper reports a continuation of the study of the effects of the interstitial elements carbon, nitrogen, oxygen and hydrogen on the weldability, or as-welded ductility, of titanium and its alloys. Two alpha-beta alloys of titanium were used as the base materials for interstitial addition. The Ti-7% Al-3% Mo alloy was fabricated in 13 interstitial analyses and the Ti-6% Al-4% V alloy was fabricated in 22 analysis combinations.

Each alloy plus interstitial additive "heat" was mechanically evaluated as 0.062-in. sheet in the following thermal history conditions: pilot, as-welded and after three different postweld heat treatments. Mechanical evaluation was performed with (1) tension and (2) free-bend transverse-weld tests. "Weldability" of each heat was established by these tests. Briefly, the results indicated that the Ti-6% Al-4% V is considerably more weldable than Ti-7% Al-3% Mo. Heats containing only 0.100% C + N_2 + O_2 interstitial in the latter alloy were only marginally weldable. The Ti-6% Al-4% V alloy can tolerate up to 0.21% oxygen. Heats containing more than 0.100% nitrogen were embrittled and as little as 0.07% carbon may add to nitrogen embrittlement. Hydrogen, for the most part, has no effect on the properties measured at analyses up to 150 ppm except in heats containing critical amounts of nitrogen or oxygen, in which case some additional embrittlement was indicated. Postweld heat treatment did not show worthwhile ductility improvement over the as-welded specimens for either base alloy.

John F. Rudy, Joseph B. McAndrew and Harry Schwartzbart are associated with Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill.

Presented at the AWS 1957 National Spring Meeting in Philadelphia, Pa., April 8-12.

Introduction

Alloy development in general is a compromise between the always desired higher strengths and the also desired adequate ductility or toughness. Titanium alloy development has been no exception. The question, "How much strengthening addition can be added before embrittlement becomes a problem?" is always before the alloy designer. The commercial alloys, consequently, are often approaching this upper strengthener addition maximum.

Unfortunately for the alloys in question, the tendency for embrittlement is enhanced by the presence of the nonequilibrium structures formed by the thermal cycle of welding. Therefore, the balance between strength and embrittlement becomes more delicate in an alloy that must be weldable. Usually, an alloy which must be weldable is designed toward the ductile side of this strengthener balance. However, in the case of titanium alloys, the three extraneous interstitial strengthener elements carbon, nitrogen, oxygen and sometimes a fourth, hydrogen, are often picked up during fabrication and may be present in sufficient amounts to cause embrittlement in the welded material.

This paper has as its subject the weldability effects of additions of the interstitial elements to two alpha-beta titanium alloys. To accomplish this study, several interstitial content variations of the two commercial alpha-beta base alloys, Ti-7% Al-3% Mo and Ti-6% Al-4% V were produced. These alloys were reduced to $^1/_{16}$-in. sheet and mechanically evaluated in the pilot, the as-welded and three postweld heat-treated conditions. The results of the mechanical testing were used as the measure of "weldability." Generally, when the as-welded properties of the base plus interstitial alloy became appreciably inferior to the properties of the low interstitial base heat, the limit of weldability was said to have been reached. It is recognized, however, that the final measure of weldability must be made in terms of the end application; and it is entirely possible that our higher purity base alloys would *not* be considered weldable for some applications, while the very high interstitial alloys may be satisfactory for others. None of the interstitial alloys were embrittled to the extent that weld bead cracks were produced by cooling stresses.

Procedures

Preparation of Alloys

The details of the melting and fabrication of the desired alloys have been given in previous reports[1, 2] and only a brief outline will be repeated here. The proper mixture of titanium sponge plus powdered master alloy and pure metal additions to give the alloy compositions listed in Tables 1 and 2 were mixed and fed into an inert-gas-atmosphere tungsten-arc melting furnace. This first melt ingot, 3 in. in diameter, approximately 7 in. in height and weighing approximately 10 lb, was then cleaned and forged down to a $1^1/_4$-in. diam rod which was used as the consumable electrode for the second melting operation. The purpose of the double melting procedure was to obtain greater homogeneity. This ingot was then forged to a $^1/_2$-in. slab and hot rolled to a final ($^1/_{16}$ in.) size. The sheets were then cut into mechanical test specimen blanks which were vacuum annealed to reduce the hydrogen to less than 50 ppm. One half of each heat was then hydrogenated to approximately 150 ppm in a Sievert's-type apparatus.

Welding

Welding was accomplished with the inert-gas-shielded tungsten-electrode arc-welding process using a trailing shield and an inert-gas backing bar to protect both the top and underside of the weld bead from atmospheric contamination. Welding was simplified mechanically by melting a bead along a solid sheet instead of butt joining two sheets. Starting and stopping tabs were used to eliminate edge defects and the heat parameters were adjusted as follows to give a 100% penetration bead with a single pass:

Current, amp	110–120
Arc voltage, v	Approx. 18
Travel speed, ipm	23
Torch flow of helium, cfh	20
Trailing shield and underside flow of helium, cfh	30

The welds obtained were sound and uniform and little difficulty was experienced with porosity or weld cracking. The welding fixture is pictured in Fig. 1, which shows the carriage-mounted torch, the trailing shield and the specimen hold-down clamps.

Mechanical Testing

Two mechanical property tests were used to measure weldability, the tensile

Table 1—Composition and Mechanical Properties of the Ti–7% Al–3% Mo Alloy Heats

						Free bend		Tensile		
Heat No.	*Condition*	*$C + N_2 + O_2$, wt. % nominal*	*C, wt. % nominal*	*N_2, wt. % nominal*	*O_2, wt. % nominal*	*End distribution in.*	*Fracture zone†*	*Ultimate strength, psi*	*Elongation in 1 in., %*	*Fracture zone*
1	Pilot	0.261	0.087	0.087	0.087	0.75		170,500	6.2	
1	Weld					4.49	HAZ*	†		
2	Pilot	0.260	0.060	0.100	0.100	3.49		†		
2	Weld					4.62	BM	†		
3	Pilot	0.260	0.100	0.060	0.100	3.37		†		
3	Weld					4.00	HAZ*-BM	161,000	1.5	HAZ
4	Pilot	0.260	0.100	0.100	0.060	4.50		†		
4	Weld					4.75	HAZ*	180,000	3.1	
5	Pilot	0.330	0.110	0.110	0.110	0.81		178,100	3.1	WM
5	Weld					4.75	HAZ*-WM	†		
6	Pilot	0.340	0.060	0.140	0.140	4.25		†		
6	Weld					4.25	BM	138,500	3.1	BM
7	Pilot	0.340	0.140	0.060	0.140	5.00		†		
7	Weld					5.00	HAZ*	†		
8	Pilot	0.340	0.140	0.140	0.060	5.00		†		
8	Weld					4.75	WM	147,000	0	WM
9	Pilot	0.420	0.140	0.140	0.140	3.50		†		
9	Weld					5.12	WM-HAZ*	†		WM
10	Pilot	0.420	0.060	0.180	0.180	0.56		171,200	10.9	
10	Weld					3.62	BM	197,600	1.5	WM
11	Pilot	0.420	0.180	0.060	0.180	2.62		143,000	1.5	
11	Weld					4.75	BM	170,000	0	BM
12	Pilot	0.420	0.180	0.180	0.060	0.56		182,200	6.2	
12	Weld					4.62	WM	149,000	3.1	BM
13	Pilot	0.104‡	0.038‡	0.013‡	0.053‡	0.69		148,500	5.4	
13	Weld					1.89	WM-HAZ*	145,000	2.8	WM

† Defective specimen.
‡ Actual analysis.
* HAZ = heat-affected zone; BM = base metal; WM = weld metal.

Table 2—Compositions of Ti–6% Al–4% V Alloy Heats

Heat designation	*C, wt. %*	*N_2, wt. %*	*O_2, wt. %*	*$N_2 + O_2$, wt. %*	*$C + N_2 + O_2$, wt. %*	*H_2, ppm*	
						Low	*High*
D	0.043	0.023	0.080	0.103	0.146	24	157
M	0.053	0.018	0.151	0.169	0.222	10	121
N	0.033	0.017	0.175	0.192	0.225	12	140
K	0.036	0.030	0.160	0.190	0.226	20	110
L	0.081	0.018	0.134	0.152	0.233	7	118
S	0.046	0.048	0.210	0.258	0.304	22	155
O	0.027	0.160	0.069	0.229	0.256	10	104
P	0.072	0.116	0.074	0.190	0.262	12	158
R	0.069	0.108	0.094	0.202	0.271	16	132
J	0.036	0.096	0.163	0.259	0.295	5	128
T	0.043	0.131	0.134	0.265	0.308	18	155

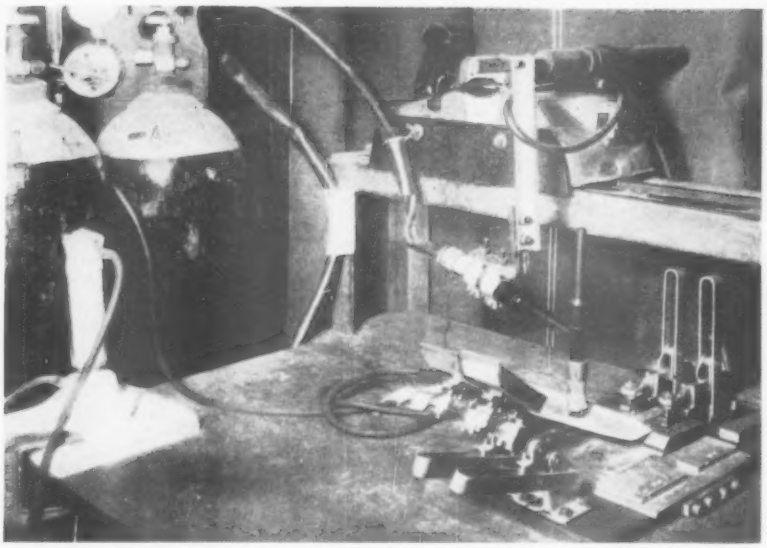


Fig. 1 Welding apparatus showing the carriage-mounted welding torch, the trailing shield and the specimen hold-down clamps which also act as the sides to the trailing shield

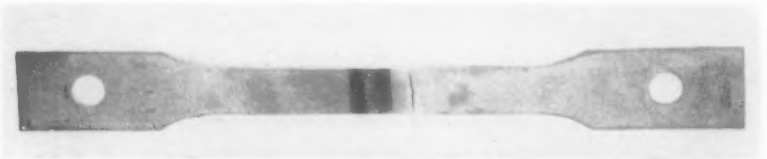


Fig. 2 A typical tensile specimen showing the undeformed weld-affected areas and the reduction of area in the base metal fracture area

test and the free-bend test. Weld specimen geometry for each was such that the major stresses were transverse to the direction of welding, giving approximately a uniform stress on each zone of the joint cross section but not necessarily a uniform strain. The results, therefore, indicate the strength and ductility properties of the weakest area. The two tests were largely supplementary. For example, the specimens with a given composition and thermal history which failed with less than 3% elongation in 2 in. in the tensile test did not fold to the required end distance of less than one inch in the free-bend test. Conversely, tensile specimens showing greater elongations were able to fold to less than one inch. (The arbitrary criterion for weldability acceptance was that the welded specimens must withstand a fold to an end distance of 1 in. or less before failure.)

A typical tensile-test specimen is shown in Fig. 2. It can be seen that almost all of the plastic flow occurred in the base metal and final failure occurred at some distance from the weld-affected zones. This particular specimen elongated 4% in the total 2-in. gage length, but the actual ductility exhibited by the failure area itself would have been much greater in the absence of the more rigid weld bead. The ductility of the weld area itself was not measurable since its yield point was not exceeded by the test. However, it would not be expected to flow appreciably.

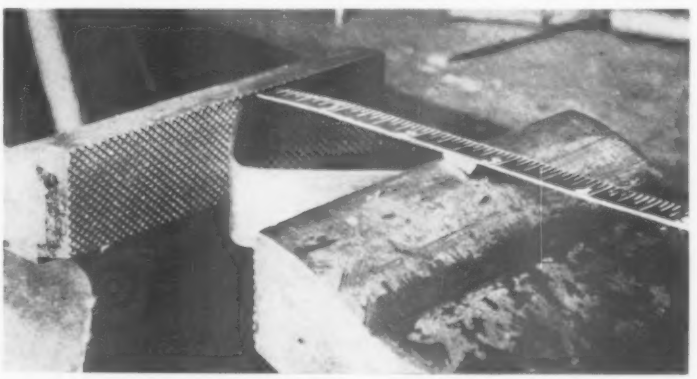


Fig. 3 Free-bend test showing the method of bending to failure and recording the "end distance" which is a measure of ductility

The free-bend test gave the same general indication of stronger and possibly less ductile weld-affected area surrounded by weaker and ductile base metal in the weldable heats. Figure 3 shows the simple method used to determine the end distance in the free-bend test. The vise was closed on the specimen until cracking occurred. The end distance was then measured and recorded. Two typical tested specimens are shown in Fig. 4. The specimen on the left is an all-alpha alloy which maintains an appreciable amount of property uniformity over the entire weld cross section, as evidenced by the general roundness of the specimen showing some plastic flow in the weld metal (WM), the heat-affected zone (HAZ) and the base metal (BM). The right-hand specimen, by contrast, assumes what the authors have called a "square-bottomed U" shape after bending. This is a typical welded-bend specimen from the Ti–6% Al–4% V alloy. The weld metal and the heat-affected zone are not plastically deformed by the stresses imposed by the test and remain straight. All of the plastic deformation occurs at the nebulous junction between the heat-affected zone and the base metal. Therefore, in this case, when a specimen is considered weldable by the authors' definition (<1 in. end distance) it means that the following conditions have been met:

1. That the base metal is ductile enough to deform the amount required to obtain small end distances. This requires considerable local ductility since the areas of strain are limited by the higher yield point weld area.
2. That the weld area (weld metal and heat-affected zone) is strong enough to develop the deforming load required without brittle failure.

These results give a good measure of what might be termed "the engineering usefulness of the joint," excepting, of course, other considerations such as cyclic or notched loading. Again, as in the tensile test, the ductility of the weld area is not measurable because its yield point is not exceeded. With the above reservations, the free bend end distance served as a very useful measure of weldability when coupled with careful observations of the final configuration, failure zone, plastic flow zone and fracture surface of the specimen.

Discussion and Results

Ti–7% Al–3% Mo Alloy

Originally, this alloy was chosen as the base alpha-beta alloy to be used for the

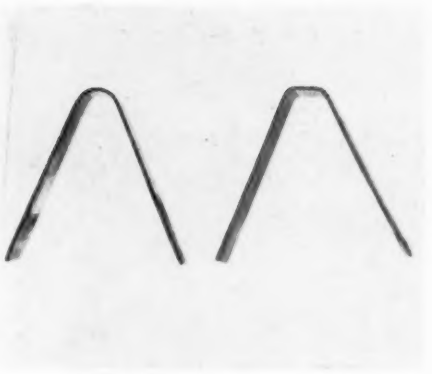


Fig. 4 Typical free-bend specimens showing the uniform deformation of the alpha alloy on the left compared to the Ti – 6% Al – 4% V specimen which does not deform in the weld-affected areas. The latter configuration is called a "square-bottomed U"

combined interstitial effect study in spite of the fact that previous investigation[2] of singular element additions to Ti – 7% Al – 3% Mo had shown that relatively small amounts seriously reduce weldability. Briefly, the individual maxima for weldability were found to be: carbon 0.08%, nitrogen 0.09% and oxygen somewhat more tolerable at up to 0.15%. These maxima, however, required postweld heat treatment for weldability. The nominal compositions of the preliminary interstitial combination heats which were fabricated are listed as the first 12 heats in Table 1 along with the pilot and as-welded free-bend and tensile-test results. These data show that the tolerance of the Ti – 7% Al – 3% Mo alloy is so low as to discourage an investigation of combined interstitial effects since even the 0.260% total $C + N_2 + O_2$ alloys exhibited low ductility as-welded fractures with free bend distances on the order of 4 in. Therefore, it was concluded that, in the interest of commercial feasibility, the Ti – 6% Al – 4% V alloy should be substituted as the base alpha-beta alloy.

Heat No. 13 of Table 1, Ti – 7% Al – 3% Mo alloy, was fabricated with no intentional interstitial addition to recheck the weldability of the higher-quality base alloy. This heat was analyzed and found to contain 0.038% C, 0.013% N_2 and 0.053% O_2. By the criterion of folding to less than one inch in the free-bend test, even this heat is only marginally weldable. Two as-welded specimens folded to 1 in. or less but the remaining seven specimens failed at between 1 and 4 in. end distance which is unsatisfactory. No marked improvement was obtained by employing the following three postweld heat treatments: (1) 1600° F/8 hr → WQ, 1025° F/16 hr → WQ; (2) 1600° F/15 min → WQ; and (3) 1600° F/8 hr → WQ.

It was intended that this base alloy be fabricated and tested at three hydrogen levels varying from less than 50 to 200 ppm. However, the desired hydrogen levels were not obtained and the highest (67 ppm) was not critical.

The conclusion indicated by this short study of the Ti – 7% Al – 3% Mo alloy is that if the alloy is to be welded, every effort must be made to keep the interstitials as low as possible. This substantiates earlier findings by other investigators.[2] Other alloys should be obtained, if possible, for an application requiring weld joint ductility.

Ti – 6% Al – 4% V

The investigation of the Ti – 6% Al–4% V alloy includes the effects of carbon, nitrogen, oxygen and hydrogen, both individually and in combinations, as well as the effects of three postweld heat treatments. These heats are listed in Table 2. This includes so many variables in relation to the number of alloy heats as to preclude convenient plotting of weldability vs. a single composition or thermal cycle parameter. Instead, the data are illustrated in several systems of sequence in bar graph form in Figs. 5 through 12.

Total $C + N_2 + O_2$%. Figure 5 illustrates the result of an attempt to explain weldability or mechanical property in terms of the simplest composition parameter, total weight percent of carbon plus nitrogen plus oxygen. The upper bars represent tensile data and the lower bars represent end distance in the free-bend test. Pilot properties can be compared with as-welded mechanical properties by observing each double column individually. The left-hand or cross-hatched half of each bar represents pilot data and, as expected, these specimens generally show more ductility than the as-welded specimens, shown as solid bars on the right-hand half. The bars are arranged in order of increasing $C + N_2 + O_2$. The most useful mechanical properties for comparative purposes are the free-bend end distance and the tensile elongations of the *as-welded* condition. While, as expected, there is a general tendency for strength

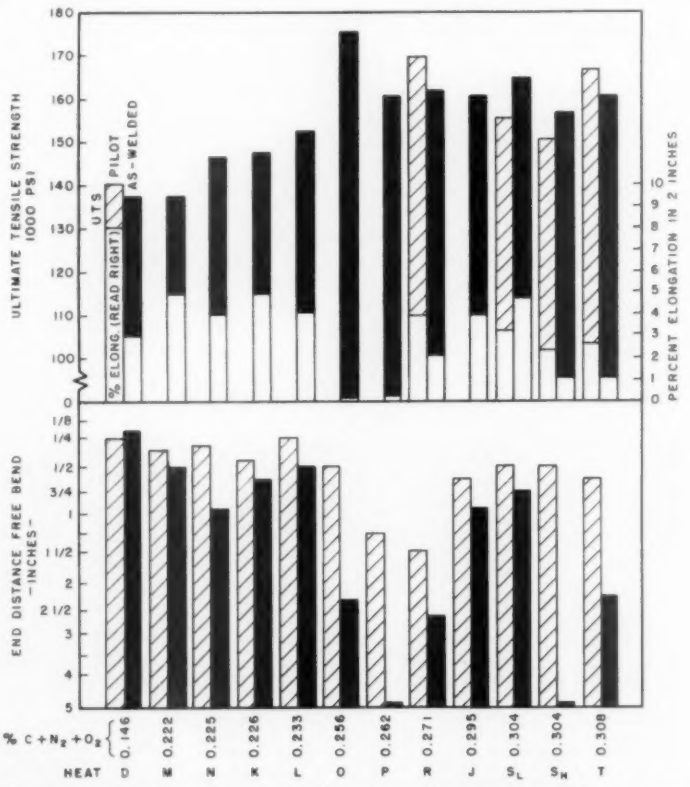


Fig. 5 Tensile (*upper*) and free-bend (*lower*) properties of both pilot and as-welded specimens arranged in order of increasing $C + N_2 + O_2$%

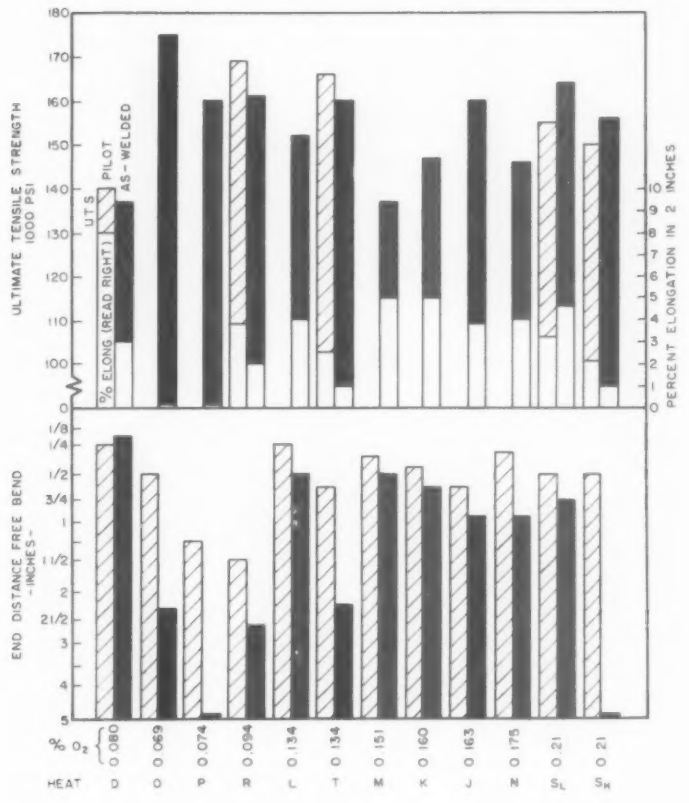


Fig. 6 Tensile (*upper*) and free-bend (*lower*) properties of pilot and as-welded specimens arranged in order of increasing oxygen. Brittleness of heats O, P, R, T and S_H is not due to oxygen

to increase at the expense of ductility with increasing total interstitial, this tendency is by no means regular. For example, by observing Heat "J," 0.295% total, or heat "S," 0.304% total, it would be concluded that approximately 0.300% can be tolerated for weldability. However, heats "O," "P" and "R," with only 0.256 to 0.271% total do not substantiate this conclusion. A similar presentation could be made on the basis of total *atomic* percent vs. mechanical properties with the same inconclusive results. From these data it is concluded that the interstitial parameter is more complex than simply $C + N_2 + O_2$ total percent.

Oxygen. Figure 6 illustrates the same data arranged in order of increasing oxygen percent. Each double bar represents pilot data on the left and as-welded data on the right as in Fig. 5. The arbitrary criteria of weldability used were that the tensile elongation of the welded sample should exceed 3% in 2 in. and that the end distance in the free-bend test of the welded sample should be 1 in. or less. By these criteria it can be seen that weldability is obtained in some heats at the high oxygen extreme of the illustration (i.e., heat S_L with 0.21% O_2) while several heats at the low end (i.e., heats O, P, R and T with 0.13% O_2 or less) are not weldable. This indicates that the higher-oxygen heats obtained are still weldable in some conditions. The low-oxygen-level, poor-weldability heats are explainable in terms of nitrogen which is discussed below.

Nitrogen. Figure 7 illustrates the same data arranged in order of increasing nitrogen content. Each double bar represents the same comparison of pilot vs. as-welded properties as in Figs. 5 and 6. These data show the most uniform dependence of mechanical properties on composition parameter, with a general decrease in weldability with increasing nitrogen. The pilot specimens maintain acceptable ductility up to the extreme of 0.160% N_2, but the as-welded specimens become borderline at 0.096% N_2 and unsatisfactory without exception at higher values of 0.108% or greater. Heat S_H is embrittled with only 0.048% N_2 but this is evidently due to O_2 or H_2

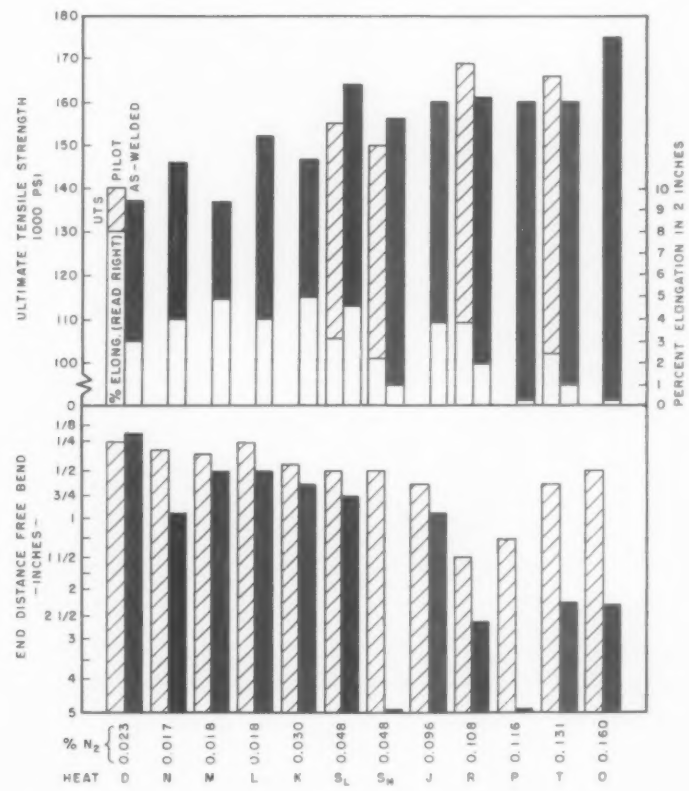
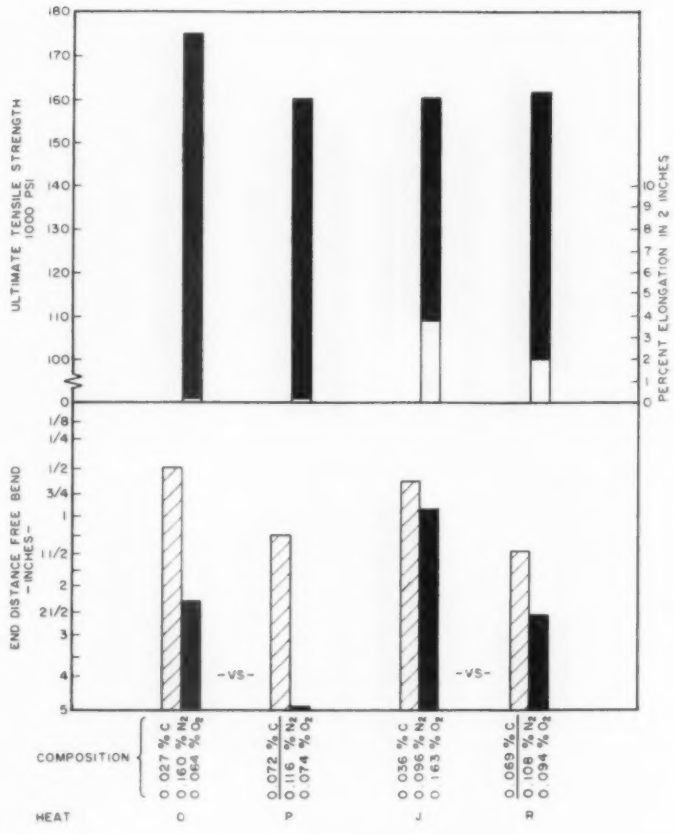


Fig. 7 Tensile (*upper*) and free-bend (*lower*) properties of pilot and as-welded specimens arranged in order of increasing nitrogen content. All heats except S_H which exhibit weld embrittlement contain greater than 0.096% N_2

Fig. 8 Tensile (*upper*) and free-bend (*lower*) properties of pilot and as-welded specimens. Heats P and R show less ductility than heats O and J, respectively, which may be due to moderate carbon analysis variations

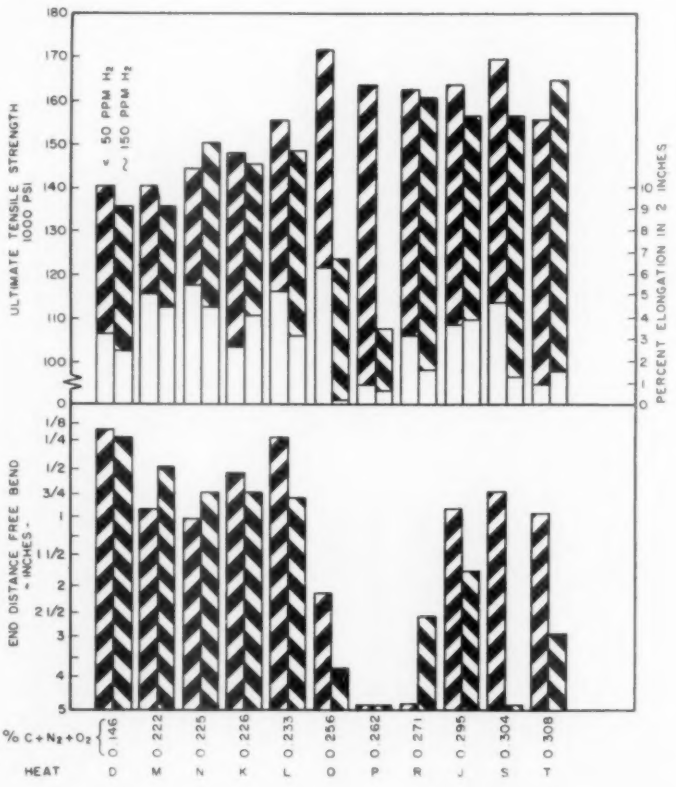


or both. The irregular dependence of weld ductility of the four or five highest N_2 heats (J, R, P, T and O) may be explained by carbon presence as discussed below.

Carbon Effects. The study of the contribution of carbon to weld embrittlement was hampered by the apparent loss of this alloying element during melting and fabrication. The initial list of desired compositions included several alloys in excess of 0.100% C. However, the actual alloys contained only 0.081, 0.072 and 0.069% carbon in the three highest carbon heats. Thus, a complete case for carbon as a Ti–6% Al–4% V weld embrittlement agent was not obtained. However, some comparisons can be made which indicate that carbon does have an effect at relatively low levels. For example, compare heats O and P in Fig. 8. Their compositions are similar for oxygen but Heat O has considerably more nitrogen (0.16%) than Heat P (0.116%) which should render Heat O more brittle. However, the opposite is true and the only apparent cause is the difference in carbon content. This indicates that the 0.072% C in Heat P is high enough to have some effect. Figure 8 also compares the data of Heat R (0.069% C) with Heat J (0.036% C). Heat R, having considerably less oxygen and only slightly more nitrogen, is much less ductile, which indicates an effect of 0.069% carbon. Heat L, which has the highest carbon (0.081%) is not deleteriously affected, but its nitrogen is very low (0.018%) and oxygen is only moderate (0.13%).

Hydrogen. Figure 9 illustrates the mechanical property data presented so as to give a picture of the effect of approximately 150 ppm hydrogen. All data in this figure are for the as-welded condition, and each double column represents the low-hydrogen (less than 50 ppm) group on the left and the high hydrogen (approximately 150 ppm) on the right. In comparing the two halves of each double column it is observed that usually the difference is not great. In the free-bend test the alloys containing up to 0.233% C + N_2 + O_2 do not show any real hydrogen effect. Some of the higher interstitial heats tend to have less free-bend ductility after hydrogenation. However, in many cases these data are not substantiated by the tensile

Fig. 9 Tensile (*upper*) and free-bend (*lower*) properties of low H_2 and high H_2 welded specimens. Each pair of bars shows the effect of H_2 on a heat



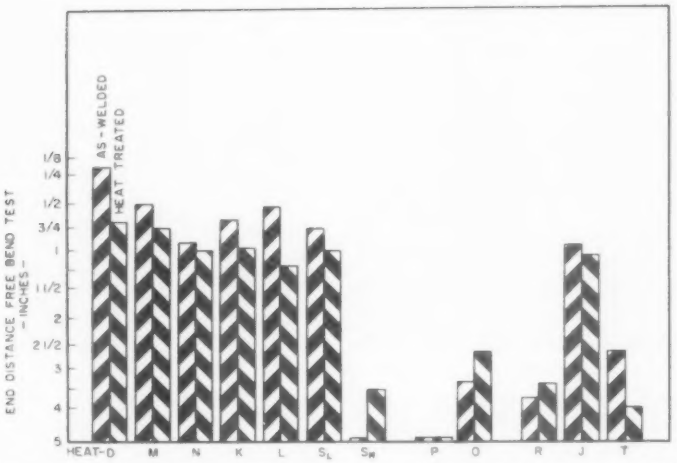


Fig. 10 As-welded *vs.* 1100° F, 20 hr → WQ postweld heat-treated free-bend ductility for the Ti – 6% Al – 4% V alloys

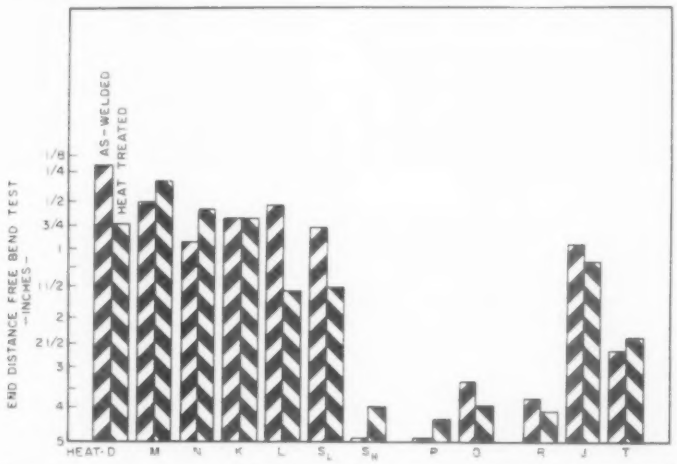


Fig. 11 As-welded *vs.* 1100° F, 1 hr → WQ postweld heat-treated free-bend ductility for the Ti – 6% Al – 4% V alloys

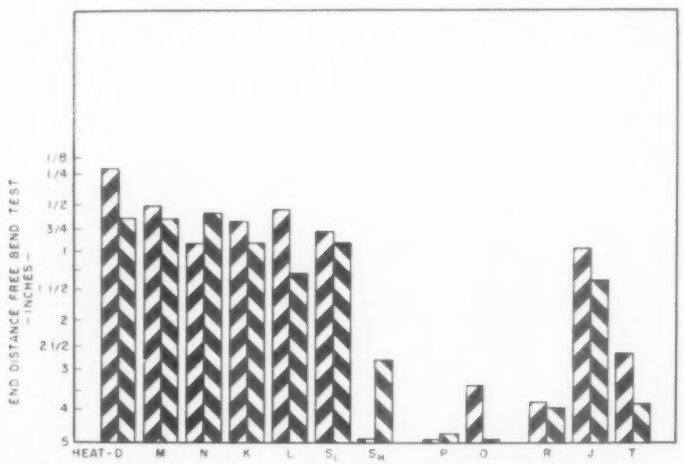


Fig. 12 As-welded *vs.* 850° F, 20 hr → WQ postweld heat-treated free-bend ductility for the Ti – 6% Al – 4% V alloys

elongation data. Thus heats S and O stand out as the spectacular indication of a hydrogen effect, with heats J and T showing a possible effect also. Heat R indicates a ductility improvement with added H_2 in the free-bend test but this is not repeated in the tensile elongation data. These heats are all somewhat borderline as regards being embrittled by either N_2 or O_2 and evidently in these cases the H_2 has some deleterious effect. However, the very ductile or the very brittle heats show no noteworthy effect. It should be mentioned that other investigators[3] have shown a dependence on loading rates slower than were used in this study.

Postweld Heat Treatment. The thermal cycle of welding leaves the material of the weld bead and the heat-affected zone in a nonequilibrium martensitic structure which is stronger and less ductile than the unaffected base metal. In the low-interstitial heats, this mechanical property change is not enough to embrittle the weld joint as shown by the free-bend test results. However, with increasing interstitials, this embrittlement becomes excessive and restricts the usefulness of the alloy.

Thus the value of a postweld heat treatment to obtain a more desirable structure is immediately obvious. The following three postweld heat treatments were employed for the Ti – 6% Al – 4% V alloy: (1) 1100° F/20 hr → WQ, (2) 1100° F/1 hr → WQ and (3) 850° F/20 hr → WQ. Both of these heat-treat temperatures are in the alpha plus beta field and should tend to transform the martensitic structure. However, it is well known that these transformation rates are very slow for titanium alloys. The heat treatments used were partially dictated by commercial feasibility.

Figures 10, 11 and 12 summarize the results of each of these three heat treatments on each of the 11 alloy heats. In these figures the left-hand half of each double bar represents the as-welded properties and the right-hand half represents the properties after the indicated postweld heat treatment. For the sake of brevity, only free bend data are shown since these are adequate to illustrate the general effects. A study of these figures indicates no general ductility improvement by any of the three heat treatments. In order to evaluate each heat treatment the general improvement in each heat across the whole range of interstitials must be considered. Almost as many heats were slightly embrittled by the treatments as were slightly improved, indicating that probably experimental scatter is the primary cause of variation.

Figure 13 shows the martensitic structure of a typical low interstitial Ti – 6% Al – 4% V weld bead in the four condi-

tions: as-welded, and after 1100° F/20 hr → WQ, 1100° F/1 hr → WQ and 850° F/20 hr → WQ postweld heat treatments. It can be seen that no appreciable microstructural change is discernible.

Summary and Conclusions

The purpose of this investigation was to continue the study of the effects of the interstitial elements carbon, nitrogen, oxygen and hydrogen on the weldability of titanium and its alloys.

Two base alloys were used as the starting point for interstitial addition; both were alpha-beta alloys. The first alloy, Ti – 7% Al – 3% Mo, received only limited attention because preliminary tests showed it to be, at best, marginally weldable with zero intentional interstitial additions, and the smallest addition was enough to seriously affect its engineering usefulness. The low-interstitial heat, which contained only 0.038% C, 0.013% N_2 and 0.053% O_2, did not fold consistently to less than one inch in the free-bend test after welding.

The second alloy, and the one on which most of the experimental work was done, was the commercially available Ti – 6% Al – 4% V alpha-beta alloy. This alloy was found to have a much greater tolerance for interstitial elements and a systematic study of its postweld properties with interstitial element additions was accomplished. The results indicated that the properties of the base alloy are not seriously impaired by as much as 0.17 to 0.20% oxygen, or up to 0.100% nitrogen. Carbon additions were lower than intended, and no alloy was produced which showed embrittlement caused by carbon alone. The highest carbon analysis obtained wa 0.081% which had no deleterious effects in the presence of subcritical oxygen and nitrogen percentages. However, two heats containing slightly over 0.100% nitrogen did indicate a slight additional embrittlement effect by carbon on the order of 0.070%.

Hydrogen up to 150 ppm does not appear to have a marked embrittling effect upon otherwise weldable alloy heats. One heat containing 0.21% oxygen did show considerable embrittlement when hydrogen was added; and another heat which had decreased ductility with 0.160% nitrogen suffered further embrittlement with hydrogen addition. Generally, however, 150 ppm hydrogen was not deleterious to the high-loading-rate mechanical properties which were measured.

The question of whether the effect of an interstitial element adds to or subtracts from the effect of another interstitial element is shown by the data to be complex and has no simple answer.

In one instance, hydrogen plus oxygen indicated an additive effect. Two other comparisons indicated an additive effect of carbon and nitrogen in combination. Another heat indicated that nitrogen plus oxygen are not additive. However, these questions should be further studied with heat analyses carefully controlled to approximately 80 to 95% of each individual element maximum. It appears that slightly subcritical amounts may be additive when combined in the same heat.

None of the six separate postweld heat treatments which were performed on the interstitial additive variations of the two base alloys gave a consistent property improvement.

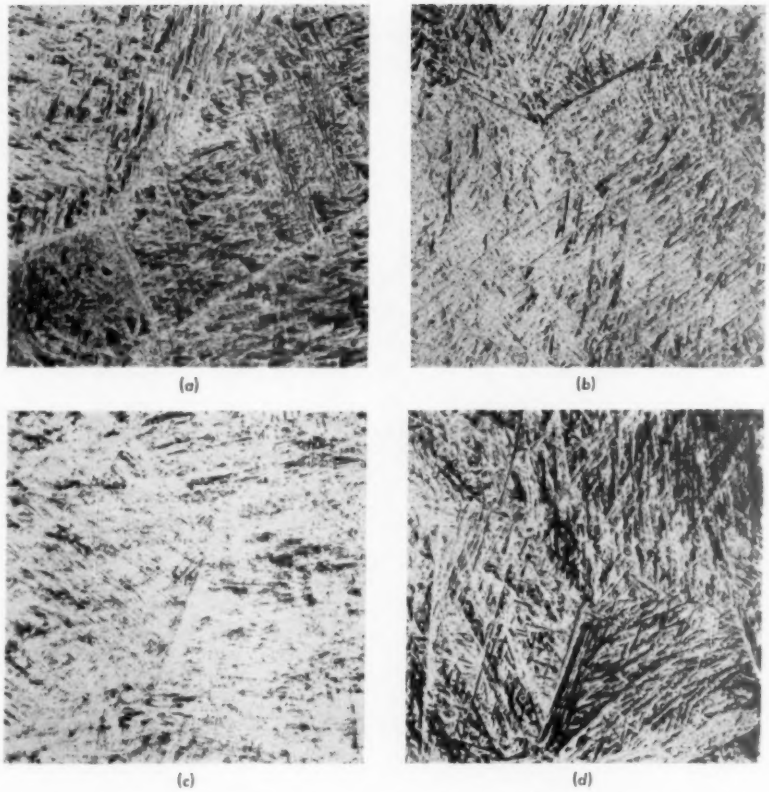


Fig. 13 Weld metal microstructures, Ti – 6% Al – 4% V plus residual interstitials (heat D). Thermal history is indicated. Etchant: 60 cc glycerin, 20 cc nitric acid, 20 cc hydrofluoric acid. Magnification X 150

(a) weld metal, as-welded, martensitic. (b) weld metal; weld, 1100° F/20 hr → WQ; martensitic. (c) weld metal; weld, 1100° F/1 hr → WQ; martensitic. (d) weld metal; weld, 850° F/20 hr → WQ; martensitic.

Acknowledgments

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THE WELDING OF MAGNESIUM ALLOYS

Paper for IIW meeting presents the latest information on the metallurgy, static properties and welding characteristics of the commercial magnesium alloys currently used in the USA

BY PAUL KLAIN

ABSTRACT. The magnesium alloys currently used in the USA and the effects of alloying elements on their welding characteristics are discussed. Both the older alloys used for room temperature and the newer alloys developed for elevated temperature service are covered. Their weldability, metallurgy and properties are discussed. A discussion of the various welding methods now in use and the conditions for use of the new inert-gas consumable-electrode method are also included.

Introduction

The purpose of this paper is to present the latest information on the welding characteristics and properties of the commercial magnesium alloys in current use in the USA. A brief outline of the welding methods most widely practiced in the USA together with a brief discussion of the new consumable-electrode are process is also reported.

Extreme lightness is one of the best characteristics of magnesium. It has a specific gravity of 1.74 which may vary to 1.83 in its alloys. Of the light metals, aluminum is $1^1/_2$ times heavier while titanium is about $2^1/_2$ times heavier than magnesium. Magnesium alloys have excellent machineability, hot formability, weldability, and high strength-to-weight ratio.

Today, almost all industries realize the importance of lightweight and are constantly searching for ways to reduce weight to move things rapidly and with the least effort and cost. As a consequence, magnesium is finding increasing uses in the aircraft, materials handling, transportation, textiles, tooling plate and other basic industries where reduction in weight or good workability are of recognized importance.

One of the impressive things about magnesium is its limitless supply in nature. One cubic mile of sea water contains 12 billion pounds of magnesium. Currently, almost all of the magnesium in the USA is produced from sea water. To supply more and cheaper wrought products, The Dow Chemical Co., sole producer of magnesium in the USA, embarked on a major expansion program in 1951 and acquired new mills capable of producing sheet in widths up to 72 in., extruded products from presses ranging from 250 to 13,200 ton capacities, and greatly expanded its alloy ingot capacity.

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Paper presented at the July 1, 1957 meeting of the International Institute of Welding, Essen, Germany.

Table 1—Relations of Thermal Properties in Magnesium and Aluminum. Data from ASM Handbook, 1948

	Magnesium		*Aluminum*		*Ratio by volume*
Property	*By weig't*	*By volume*	*By weight*	*By volume*	*Al to Mg*
Heat of fusion	89 cal/g	155 cal/cm³	94.6 cal/g	255 cal/cm³	3:2
Specific heat	0.25 cal/g	0.44 cal/cm³	0.22 cal/g	0.58 cal/cm³	4:3
Thermal conden-sation	0.38	0.38	0.53	0.53	
		cal/cm ° C/sec		cal/cm ° C/sec	3:2
		Coefficient of Thermal Expansion			
20–100° C	26.0 × 10^{-6} in./in. − ° C		24.0 × 10^{-6} in./in. − ° C		
68–212° F	14.3 × 10^{-6} in./in. − ° F		13.3 × 10^{-6} in./in. − ° F		

Properties Important to Welding

When heated in air to its melting point, magnesium tends to oxidize rapidly and, therefore, when welding, it requires protection by an inert gas such as helium or argon or a flux cover. The welding fumes from all of the commercial alloys, except those containing thorium, are neither harmful nor toxic. The welding fumes from the thorium alloys are toxic if inhaled over a long period of time but the concentration of thorium in the fumes is sufficiently low so that good ventilation or local exhaust provide adequate protection. No radiation hazard is involved in the handling of thorium alloys.

The heat required to melt magnesium is 89 cal/g. A comparison of the amount of heat necessary to weld aluminum and magnesium is given in Table 1. Magnesium requires approximately two-thirds the heat of aluminum for fusion of equal volumes. Its high thermal expansion and conductivity require good tooling and forms for holding the parts in alignment during welding.

Magnesium possesses limited workability at room temperature, but at elevated temperatures, from 400 to 600° F, magnesium alloys can be more severely worked than the other structural metals at room temperature. The ease of working obtained at elevated temperatures has proved extremely useful in stress relieving and straightening of weldments.

Fire hazard when welding magnesium alloys due to self ignition is extremely remote. No fires have ever been reported as having been caused by welding. Magnesium fires more often result from other causes, such as grinding dust, mill shavings, borings or routing chips unless good housekeeping is maintained.

The corrosion resistance of unpainted, currently used commercial alloys has been good in normal service, as exemplified by welded dockboards and ladders. For maximum protection, a suitable paint system should be used with a prepaint chemical treatment. Electroplating may also be used. To prevent galvanic corrosion, paint, oil and insulating tapes are used between dissimilar metals. The use of aluminum or cadmium and zinc-plated steel greatly reduces galvanic attack.

Some magnesium alloys, like other metals, are susceptible to stress-corrosion cracking.[1] This can be eliminated by adequate stress-relief of weldments.[2] The stress relieving and straightening operations can and are being done simultaneously.

Table 2—Composition and Physical Properties of Magnesium Alloys for Room-Temperature Use

Alloy	%Al	%Mn	%Zn	%Zr	%Others	Specific gravity	Thermal condensation cgs units (20° C)	Electrical res. microhm cm (20° C)	Solidification range, ° F
Sheet and Plate									
AZ31B	3.0	0.3	1.0	..	..	1.77	0.18	9.2	1050–1160
ZE10XA	..	..	1.2	..	0.21 RE	1.76	0.33	5.0	.....
Extruded Shapes and Sections									
M1A	..	1.2	..	..	..	1.76	0.33	5.0	1190–1202
AZ31B	3.0	0.3	1.0	..	..	1.77	0.18	9.2	1050–1160
AZ61A	6.5	0.15	1.0	..	..	1.80	0.14	12.5	990–1145
AZ80A	8.5	0.15	0.5	..	..	1.80	0.12	14.5	910–1130
ZK60A	..	..	5.7	0.55	..	1.83	0.29	5.7	930–1175
ZK20XA	..	..	2.3	0.45	..	1.78	..	..	.....
Casting Alloys									
AZ63A-T4	6.0	0.15	3.0	..	..	1.83	0.13	13.9	830–1130
AZ92A-T6	9.0	0.10	2.0	..	..	1.82	0.14	12.6	830–1110
AZ91A-T4	9.0	0.13	0.6	..	..	1.81	0.11	16.4	875–1120
AZ91C-T4	8.7	0.13	0.7	..	..	1.81	0.11	16.4	875–1120
AZ81A-T4	7.6	0.13	0.7	..	..	1.81	0.12	15.2	855–1110
AM80A-T61	8.5	0.15	..	..	..	1.80	0.15	11.2	925–1125
AM100A-T51	10.0	0.10	..	..	..	1.81	0.15	11.6	910–1100
ZK51A	..	..	4.6	0.7	..	1.81	0.25	6.7	.....

Alloying Elements

Magnesium has insufficient mechanical strength in its pure state for structural purposes and must be alloyed with other elements to obtain the desired properties. Aluminum, zinc, manganese and zirconium are the most common alloying agents in the older room temperature alloys, while rare earth metals and thorium are the chief elements used in high temperature alloys. Berryllium and calcium are used to a lesser extent.

Of the alloying additions, aluminum and zinc, either singly or in combination, effectively increase the strength of magnesium at room temperature. These elements, however, also create two undesirable characteristics. The aluminum gives rise to stress-corrosion sensitivity of welds and the zinc to severe weld cracking tendency. Manganese, beryllium and zirconium, because of their limited solubility and the formation of high mp constituents with magnesium, do not affect the welding characteristics. Calcium, even though used in small amounts, causes severe weld cracking when present in amounts exceeding 0.05%. Rare earth metals (Mischmetal) and thorium show beneficial effects on the weldability, especially in the case of zinc-containing alloys. They both appear to form high melting compounds with the zinc and thereby increase the solidus temperature to such a point that cracking is greatly reduced or completely eliminated.

Commercial Alloys

Magnesium alloys can be conveniently divided into alloys for room temperature and for elevated temperature use. The nominal compositions and physical properties of the room temperature alloys are given in Table 2 and of the elevated temperature alloys in Table 3. The ASTM alloy designations are used throughout this paper.

Wrought Alloys

The room temperature Mg-Al-Zn and Mg-Mn alloys have been in commercial use in the USA for many years. The Mg-Zn-Zr (ZK60A) high strength and the other alloys have been only recently developed within the last 10 or 15 yr. The Mg-Mn (M1A) alloy is used sparingly at the present time. It no longer is being offered as a sheet alloy due to its relatively low properties. The AZ31B alloy in the form of sheet, plate and extrusions, is the one most widely used in welded applications. It is the best all around wrought alloy combining high strength, good ductility, toughness, formability and weldability.

Table 3—Composition and Physical Properties of Magnesium Alloys for Elevated-Temperature Use

Alloy	%Th	%Zn	%Zr	%RE	%Others	Specific gravity	Thermal conductivity cgs units (100–300° C)	Electrical res. microhm cm (20° C)	Solidification range, ° F
Sheet and Plate									
HK31A	3.3	..	0.7	..	..	1.79	0.25	6.6	1092–1195
HM21XA	2.0	..	..	..	0.6 Mn	1.78	0.33	5.0	1121–1202
Extruded Shapes and Sections									
HK31A	3.3	..	0.7	..	..	1.79	..	..	1092–1195
HM31XA	3.0	..	..	..	1.5 Mn	1.81	..	..	1121–1202
Casting Alloys									
EK30A	..	..	0.35	3.3	..	1.79	0.26	6.3	1100–1184
EK41A	..	..	0.7	4.0	..	1.81	0.24	6.9	1095–1193
EZ33A	..	2.7	0.7	3.3	..	1.83	0.24	7.0	1010–1189
HK31A	3.3	..	0.7	..	..	1.79	0.22	7.7	1092–1195
HZ32A	3.3	2.1	0.7	..	..	1.83	0.26	6.5	1026–1198
ZH62A	1.8	5.7	0.75	..	..	..	..	..	.....

This alloy is of the nonheat-treatable type and depends on work-hardening effects for higher strengths. The AZ61A extrusion and forging alloy also is not heat treatable, while the AZ80A and ZK60A can be aged to increase their strengths.

Two of the most promising room-temperature, wrought alloys nearing the commercial stage in the USA are ZE10XA sheet and ZK20XA extrusions. These alloys are now being supplied in limited quantities for evaluation of production and service characteristics. Their chief advantage over the Mg-Al-Zn alloys is their insensitivity to stress-corrosion cracking after welding. This makes it possible to eliminate stress-relief treatments after welding and should prove advantageous in structures where stress-relief is difficult to apply and not necessary for straightening.

The high-temperature HK31A wrought and cast alloy of the composition shown in Table 3 was only recently developed to fill an existing need for a lightweight material of superior creep strength at temperatures up to 600° F. It is available as sheet and plate in the -H24 temper (half hard) and in the -0 temper (annealed). It can also be heat treated to the -T6 temper for better properties but it has to be done by the user. More recently, a newer alloy designated as HM21XA-T8, which does not require heat treatment by the user for maximum properties, has been announced.[3] It has improved high-temperature properties and superior creep strength over HK31A. A limited quantity is now being distributed for evaluation on production parts. Both HK31A and HM21XA possess excellent weldability.

Cast Alloys

The most widely used room-temperature cast alloys are AZ63A, AZ92A and AZ91C for sand and permanent mold castings and AZ91A for die castings. Because of their higher alloy contents, these alloys are more crack sensitive than the wrought alloys and generally require preheating prior to welding. The other room-temperature cast alloys are used to a lesser extent in the USA and, therefore, only limited welding data are available.

As shown in Table 3, the recently-developed high-temperature magnesium cast alloys require either rare earth metals in the form of "Mischmetal" or thorium as the alloying agents. The magnesium-rare earth-metal compositions are used chiefly as sand castings in applications requiring good creep strength at moderately high temperatures. The thorium-containing alloys exhibit even higher creep resistance and are used in both the wrought and cast forms for applications operating at

Table 4—Weldability Rating of Commercial Magnesium Alloys

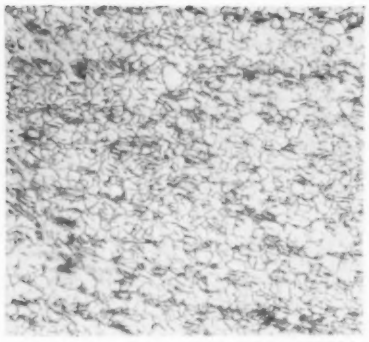
	Wrought alloys		*Cast alloys*	
Rating	*Room temp*	*High temp*	*Room temp*	*High temp*
Excellent	M1A AZ31B	HK31A HM31XA	AM100A AM80A	HK31A EK30A EK41A
Good	AZ61A ZE10XA ZK20XA AZ80A		AZ81A	EZ33A HZ32A
Fair			AZ91C	
Poor			AZ92A	
Very Poor	ZK60A		AZ63A ZK51A	

Table 5—Welding-Rod Alloys for Use on the Different Alloys to Be Welded

Welding rod alloy	*Alloys which can be welded*		
	Sheet and plate	*Extrusion*	*Casting*
	Room-Temperature Alloys		
M1A		M1A	
AZ61A	AZ31B, ZE10XA	AZ31B, AZ61A, AZ80A, ZK20XA	
AZ92A	AZ31B, ZE10XA	AZ31B, AZ61A, AZ80A, ZK20XA	AZ63A, AZ92A, AZ91C, AZ81A, AM80A, AM100A
AZ63A			AZ63A
	Elevated-Temperature Alloys		
EK41A			EK30A, EK41A, EZ33A
EZ33A	HK31A, HM21XA	HM31XA, HK31A	EK41A, EZ33A, HK31A, HZ32A
HK31A	HK31A, HM21XA	HM31XA, HK31A	HK31A
HZ32A			HZ32A

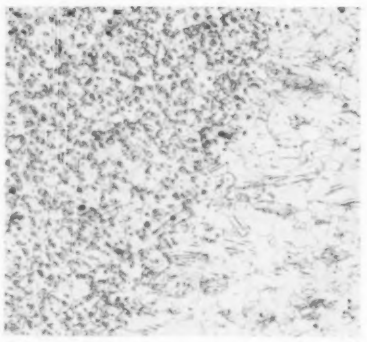
Table 6—Room-Temperature Properties of Arc-Welded Magnesium Alloys Used at Room Temperatures

		Original metal properties			*Weld properties*		
Alloy	*Welding rod alloy*	*1000 psi TS*	*1000 psi TYS*	*% Elongation in 2 in.*	*1000 psi, TS*	*% Elongation in 2 in.*	*% Efficiency*
		Sheet and Plate					
AZ31B-O	AZ61B	37	22	21	36	12	97
AZ31B-H24	AZ61B	42	32	15	37	10	86
ZE10XA-O	AZ61B	34	24	25	30	8	88
ZE10XA-H24	AZ61B	43	37	6	32	6	75
		Extrusions					
M1A-F	M1A	37	26	11	20	2	55
AZ31B-F	AZ61A	38	29	15	35	12	92
AZ61A-F	AZ61A	45	33	16	40	8	91
AZ80A-F	AZ61A	49	36	11	42	4	91
ZK20XA-F	AZ61A	39	28	7	33	5	85
		Casting Alloys					
AZ63A-F	AZ63A	29	14	6	24	2.5	83
AZ63A-T4	AZ63A	36	14	12	28	5.0	78
AZ63A-T6	AZ63A	36	19	5	30	2.0	83
AZ92A-F	AZ92A	24	14	2	24	2.5	100
AZ92A-T4	AZ92A	36	14	10	28	4.0	78
AZ92A-T6	AZ92A	36	23	2	30	2.0	83
AZ91C-F	AZ92A	24	14	2	24	2.5	100
AZ91C-T4	AZ92A	36	14	11	28	4.0	78
AZ91C-T6	AZ92A	36	19	4	30	2.0	83
AZ81A-F	AZ92A	24	14	6	24	2.5	100
AZ81A-T4	AZ92A	36	14	12	34	8	95



Acetic picral etch

Structure of $^1/_2$-in. AZ31B-F plate



Weld — Acetic picral etch

Weld junction on $^1/_2$-in. AZ31 B-F plate, AZ61A weld metal

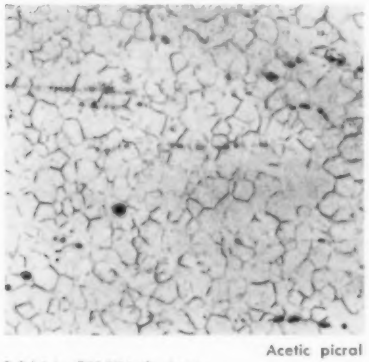
Fig. 1 Structure of $^1/_2$-in. AZ31B-F plate and weld junction, AZ61A weld metal X100

even higher temperatures than those at which the rare earth metal alloys are used. The rare earth metal and thorium-containing alloys exhibit very good welding characteristics.

A comparison of the properties of the unwelded cast AZ63A and AZ92A alloys with the high-temperature alloys at various temperatures, as shown in Table 10, serves to illustrate the superiority of the newly developed alloys at the elevated temperatures.

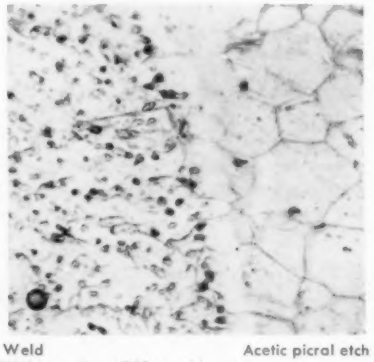
Weldability

In most magnesium alloys, an increase in alloy content generally results in an increase in the solidification range and in weld cracking tendency and in a decrease in the melting point, shrinkage and electrical and thermal conductivities. In general, the richer alloys show less grain growth in the area next to the weld and therefore show higher weld efficiencies than the low-alloy-content materials.



Acetic picral

0.064-in. ZE10XA-O sheet



Weld — Acetic picral etch

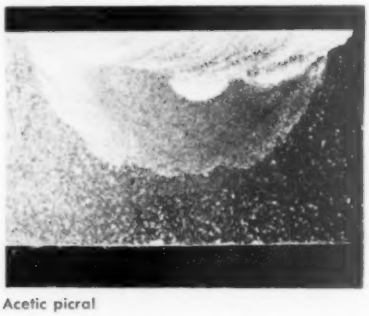
Weld junction, AZ61A weld metal

Fig. 2 Structure of 0.064 ZE10XA-O sheet and weld junction, AZ61A weld metal. X250

Table 7—All-Weld-Metal Properties of Various Rod Alloys

Rod alloy	*1000 psi TS*	*TYS*	*% Elongation in 2 in.*	*Alloy on which rod was deposited*
AZ61A	34.3	14.5	10.0	AZ31B
AZ61A	36.2	14.5	16.2	ZE10XA
AZ92A	36.8	18.9	8.0	AZ31B
HK31A	26.0	13.8	10.5	HM31XA
HZ32A	32.3	19.0	11.5	HZ32A
HZ32A	31.5	16.5	10.0	HM31XA
EZ33A	26.8	19.8	3.5	HM31XA
EK41A	26.0	17.7	5.5	HM31XA

Alloys containing up to 6% aluminum and up to 1% zinc possess good weldability, while those containing over 6% aluminum and up to 1% zinc are mildly crack sensitive. If the zinc exceeds 1% in the higher aluminum-containing alloys, weld cracking becomes severe, as in the case of cast alloys AZ63A and AZ92A. Even without aluminum, the alloys containing over 3% zinc are hot short and difficult to weld. Nearly all the high aluminum-zinc containing cast alloys, in addition to being crack sensitive, are also subject to incipient fusion of the grain boundary compound or



Acetic picral

Fig. 3 $^3/_8$-in. AZ63A-T4 welded with AZ92A rod. X5 (Reduced by $^1/_3$ upon reproduction)

Table 8—Properties of Welds in Wrought High-Temperature Alloys

Alloy	*Rod alloy*	*Testing temperature — 70° F: 1000 psi TS*	*TYS*	*% Elongation in 2 in.*	*400° F: 1000 psi TS*	*TYS*	*% Elongation in 2 in.*	*600° F: 1000 psi TS*	*TYS*	*% Elongation in 2 in.*
HK31A-H24, Unwelded	.....	35.0	21.0	23.0	22.0	21.0	36.0	11.0	7.0	86
HK31A-H24, Welds	HK31A	27.6	..	3.1	17.2	14.2	29.0	11.2	8.2	46.8
HK31A-O, Unwelded	.....	39.0	30.0	6.0	24.0	22.0	16.0	13.0	7.0	70
HK31A-O, Welds	HK31A	30.3	24.4	1.5	22.9	17.1	5.8	14.3	8.2	55.5
HM21XA-T8, Unwelded	.....	34.0	25.0	10.0	18.0	17.0	30.0	14.0	12.0	15.0
HM21XA-T8, Welds	HK31A	27.0	21.7	1.5	19.0	14.4	8.0	14.9	11.4	14.5
HM21XA-T8, Welds	HM21XA	22.2	16.3	1.5	18.2	12.9	5.5	14.6	12.3	13.5
HM21XA-T8, Welds	EZ33A	31.0	22.5	1.5	19.4	15.3	7.5	14.1	11.8	11.0
HM21XA-F, Unwelded	.....	47.0	46.0	6.0	26.0	24.0	14.0	18.0	16.0	26.0
HM31XA-F, Welds	HK31A	24.0	16.0	2.7	16.7	9.5	23.3	11.8	8.3	51.3
HM31XA-F, Welds	HM31XA	24.5	15.8	2.5	16.9	10.1	10.0	12.2	9.3	45.3
HM31XA-F, Welds	EZ33A	29.9	19.6	1.8	21.1	12.5	22.0	12.6	8.9	26.6

Table 9—Properties of Welds in Cast High-Temperature Alloys

Alloy	Testing temperature: 70° F 1000 psi TS	70° F 1000 psi TYS	70° F % Elongation in 2 in.	400° F 1000 psi TS	400° F 1000 psi TYS	400° F % Elongation in 2 in.	600° F 1000 psi TS	600° F 1000 psi TYS	600° F % Elongation in 2 in.
EK41A-T5, Unwelded	20.3	17.1	0.5	19.0	12.0	16.0	11.0	7	57
EK41A-T5, Welds	18.3	15.1	1.0						
EK41A-T6, Unwelded	24.3	17.0	4.2	19.0	12.4	12.5	11.8	7.1	70.2
EK41A-T6, Welds	22.6	14.3	6.2	20.2	10.8	9.8	10.2	6.1	27.6
EZ33A-T5, Unwelded	20.6	15.6	2.1	21.0	11.0	22.0	12.0	8.0	50.0
EZ33A-T5, Welds	20.6	16.4	1.1	18.7	11.3	13.3	10.6	6.8	50.4
HK31A-T6, Unwelded	31.0	16.0	6.0	22.0	13.0	16.0	19.0	11.0	21.0
HK31A-T6, Welds	31.0	16.5	9.5	20.0	12.4	14.4	16.5	11.2	11.3
HZ32A-T5, Unwelded	29.5	19.0	3.8	19.0	13.0	30.0	13.0	10.0	38.0
HZ32A-T5, Welds	27.5	16.7	3.8	19.4	13.1	33.0	12.3	9.6	26.3

eutectic. This results in small fusion voids in the heated zone and lowered properties. The ZK60A and ZK51A alloys fall in the class of very limited weldability with a high tendency to cracking.

The relative weldability or weld-cracking tendency of the currently used magnesium alloys is indicated in Table 4. These ratings are quite general but are based on both laboratory and production experience where available. The ratings for the wrought and cast alloys are based on techniques used when each alloy is welded to itself. When welding to other alloys, best results are obtained if alloys of the same class or as near similar physical properties as possible are matched.

The welding of cast alloys may involve the repair of casting defects or of welding to wrought materials in structural parts. Because of the crack sensitivity of the higher-zinc-containing room-temperature alloys, the practice in repair welding is to preheat the alloys to between 650 and 750° F, with care being taken not to preheat a given alloy above its solution heat treating or incipient melting temperature. Where welds are made in relatively unrestrained areas, such as on external bosses or flanges, preheating is not required and only local preheating at 300 to 500° F is sufficient. When welding castings to wrought products, preheating may be undesirable or impossible, in which case only cast alloys with a weldability rating of fair or better are used.

Limited data indicates that the rare earth metals and thorium-containing alloys can be repair welded without preheat, although in practice, they are usually preheated to about 500° F for case of welding. Welding information on the high-temperature cast alloys is not as well established as on the room-temperature alloys and, in the case of ZH62A, no information is available.

Welding Rod

The welding-rod compositions used on the different alloys are listed in Table 5. Generally, the same rod composition as the alloy to be welded or one of higher-alloy content and lower mp is used. However, for economic reasons, the number of rods is reduced to as few as possible. For the Al-Zn containing alloys, the AZ92A rod is useful on all alloys, but the AZ61A is also used on wrought alloys because of its lower cost. The welding-rod compositions for use with the high-temperature alloys have not been firmly established as yet, although indications are that EZ33A may be used on all the cast and wrought high-temperature alloys and HK31A on all thorium alloys not containing zinc.

Properties of Welds

In Table 6 are shown the properties of the alloys used at room temperature together with the preferred welding rod. In the Mg-Al-Zn system, the weld strengths of the wrought alloys are at least 90% of that of the annealed sheet or extruded base metal. In the work-hardened AZ31B alloy, the efficiency is lower, although the actual strength is equal to or slightly higher than in welds made on annealed material.

As a general rule, welded joints fail in the heat-affected zone rather than in the weld itself. This is due to the high strength of the weld metal, as shown in Table 7, as a result of its fine grain, and to the lowered strength and slight grain growth in the heat-affected zone. These effects are illustrated in Figs. 1 and 2 showing the base metal and weld joints in AZ31B and ZE10XA sheet. No significant grain growth occurs in AZ31B, thus accounting for its high

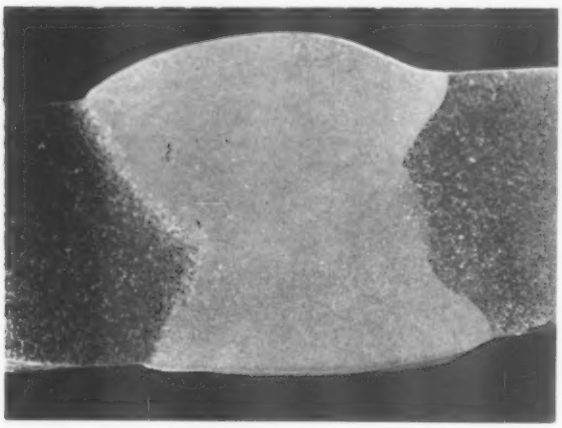
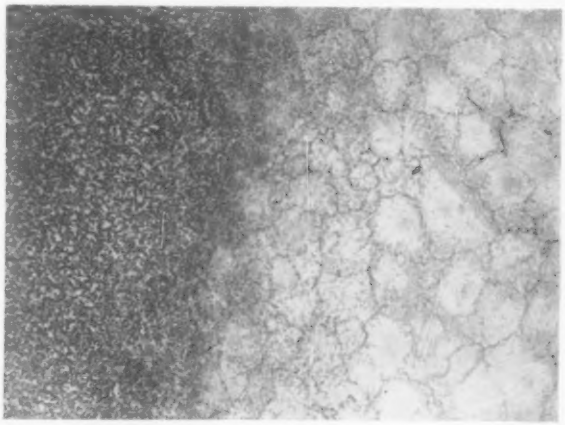


Fig. 4A 3/8-in. AZ91C-T6 welded to 3/8-in. AZ31B-F plate with AZ92A rod. X 4



Weld. Acetic picral

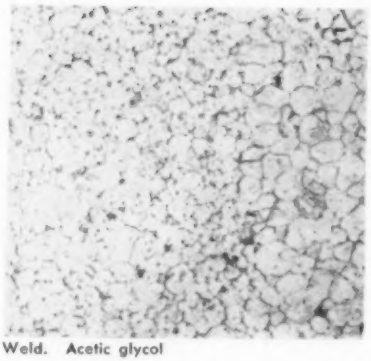
Fig. 4B AZ91C-T4 weld junction with AZ92A weld metal. X 50

strength, while the grain growth in ZE10XA is sufficient to reduce its strength to below that obtained on AZ31B welds, even though original strengths are the same.

The weld strengths of the room-temperature cast alloys AZ63A, AZ92A and AZ91C, as shown in Table 6, are lower than can be obtained due to the presence of some porosity and incipient fusion. With absolutely sound castings, weld strengths in both the -T4 and -T6 tempers attain values of 34,000 psi or 95% of the base metal, as illustrated by the values for AZ81A. Weld strengths on other cast alloys are not included due to scarcity of data.

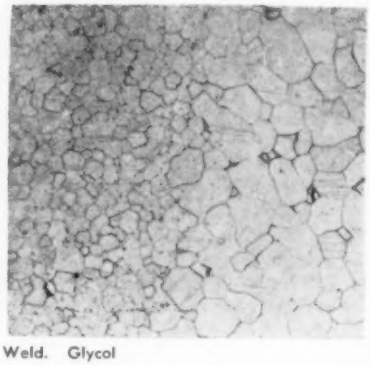
The extremely-fine grain size obtained in the welds in the Mg-Al-Zn castings with AZ92A rod are typified by the illustrations in Figs. 3 and 4 on AZ63A and AZ91C alloys. Figure 4b shows the difference more clearly at the higher magnification.

The tensile properties of the welded high-temperature alloys at room and elevated temperature as obtained on a limited number of tests are given in Tables 8 and 9. The room-temperature properties and efficiencies of the wrought alloys are low due to the annealing effect of the weld thermal cycle, but, at elevated temperatures, the welds in most alloys are as strong as the base metal. The cast alloys are not affected by the welding heat and their weld strengths are equal to the base metal. The microstructure of the weld junction in HK31A-H24 sheets with HK31A rod is shown in Fig. 5. In Figs. 6, 7 and 8 are shown the weld junctions in HK31A-F, EZ33A-T5 and HZ32A-T5 castings. Again, the extremely-fine grain size in the welds stands out. Grain growth in the heat-affected zone is shown to be very slight.



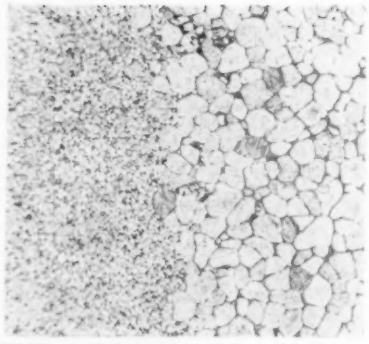
Weld. Acetic glycol

Fig. 5 Weld junction in 0.051-in HK31A-H24 sheet welded with HK31A rod. X 200



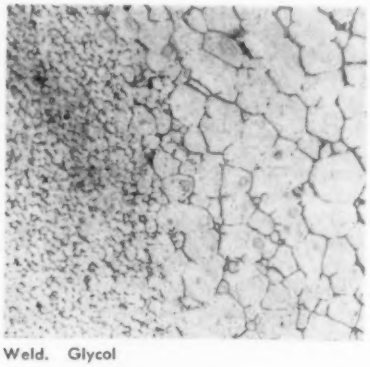
Weld. Glycol

Fig. 6 Weld junction in $^3/_8$-in. HK31A-F with HK31A rod. X 100



Weld. Acetic picral

Fig. 7 Weld junction in $^3/_8$-in. EZ33A-T5 with EZ33A rod. X 60



Weld. Glycol

Fig. 8 Weld junction in $^3/_8$-in. HZ32A-T5 with HZ32A rod. X 100

Heat Treatment After Welding

None of the wrought alloys require any treatment after welding for property improvement, but nearly all the casting alloys do require heat treatments to improve their properties. The post-weld heat treatments for the various casting alloys are shown in Table 11. Because of the fine grain size and the fine dispersion of the compounds in the weld, relatively short heating times may be used to obtain good solution heat treatment in the Mg-Al-Zn series. In the case of AZ92A, AZ81A, and AZ91C, the minimum heat-treatment time must be used to avoid excessive grain growth. Regular heat treatments can be used on the other alloys.

When post-weld heat treatment is not necessary to obtain maximum properties, stress-relief heat treatments may still be required for dimensional stability or to avoid stress-corrosion. These are shown in Table 12 for the room-temperature alloys. Only the Mg-Al and the Mg-Al-Zn series of alloys appear to be susceptible to stress-corrosion cracking after welding. Data on other alloy systems are still inconclusive but indications are that welds in aluminum-free alloys are not stress-corrosion sensitive, and therefore do not need this special treatment.

Welding Processes

The welding processes most widely used are the inert-gas tungsten-arc, the inert-gas metal-arc (consumable electrode), gas and spot welding. Other processes which can be used include brazing, soldering and, to a lesser extent, seam, flash and pressure welding.

Arc Welding

Both the tungsten and the consumable-electrode inert-gas-shielded arc processes can be used, although the latter is limited at present to the welding of heavy-gage materials.[5] In the tungsten-arc process, both the d-c electrode positive and the a-c with superimposed high-frequency current can be used as power sources for welding. Present day usage is overwhelmingly in favor of a-c high-frequency-stabilized current. D-c welding is limited to the

Table 10—Elevated-Temperature Properties of Magnesium Casting Alloys*

	—400° F, 1000 psi—			—600° F, 1000 psi—			—700° F, 1000 psi—		
Alloy	*TS*	*TYS*	*Creep strength*	*TS*	*TYS*	*Creep strength*	*TS*	*TYS*	*Creep strength*
AZ92A-T6	17	12	1.4	8	5	..	..	..	..
AZ63A-T6	18	12	..	8	6	..	..	..	..
EK30A-T6	20	12	7.6	12	8	1.2	..	..	..
EZ33A-T5	21	11	8.0	12	8	1.2	..	..	..
EK41A-T6	22	14	7.8	13	9	1.5	6	4	..
HK31A-T6	24	14	9.5	20	12	2.9	13	8	1.0†
HZ32A-T5	17	10	7.8	12	8	3.6	10	7	2.0†

For tensile tests samples held 10 minutes at temperature before testing.
Creep strength based on 0.2% total extension in 100 hr.
* Unwelded.
† 660° F.

Table 11—Heat Treatment of Castings After Welding

Alloys	Preheat temp ± 10° F(1)(5)	Welding rod	Condition (2) before welding	Desired condition after welding	Heat treatment after welding (times after reaching temperature)
AZ63A	725	AZ92A or AZ63A	-T4 or -T6	-T4	1/2 hr at 730 ± 5° F(3)
		AZ63A	-F	-T4	preheat at rate not exceeding 150°/hr from 500° F to heat treat temp +10 hr at 725 ± 5° F
		AZ92A or AZ63A	-T4 or -T6	-T6	1/2 hr at 730 ± 5° F(3) plus aging 5 hr at 425° F
		AZ63A	-F	-T6	preheat at rate not exceeding 150°/hr from 500° F to heat treat temp +10 hr at 725 ± 5° F +5 hr at 425° F
AZ92A	750	AZ92A	-T4 or -T6	-T4	1/2 hr at 770 ± 5° F (4)
			-T4 or -T6	-T6	1/2 hr at 770° F(4) + aging 4 hr at 500° F
AZ91C	750	AZ92A	-T4 or -T6	-T4	1/2 hr at 775 ± 5° F (4)
			-T4 or -T6	-T6	1/2 hr at 775 ± 5° F(4) + aging 16 hr at 320° F
AZ81A	750	AZ92A	-T4	-T4	1/2 hr at 780° F
EK30A	500	EZ33A	-T6	-T6	16 hr at 400° F
EK41A	500	EZ33A	-T5	-T5	16 hr at 400° F
		EZ33A	-T6	-T6	16 hr at 400° F
EZ33A	500	EZ33A	-T5	-T5	2 hr at 600° F + 5 hr at 420° F
HK31A	400	HK31A	-T6	-T6	16 hr at 400° F
HZ32A	500	HZ32	-T5	-T5	2 hr at 650° F + 16 hr at 600° F

(1) SO_2 atmos here recommended when preheating -F castings, not required for -T4 or -T6 castings if above temperatures are not exceeded.

(2) Condition: -F as cast, -T4 solution heat treated, -T6 solution heat treated and aged. -T5 artificially aged.

(3) Solution of compound in 15 to 30 min at temp. AZ63A castings welded with AZ63A rod can be re-solution heat treated along with unwelded AZ63A castings being given standard -T4 treatment. If AZ63A castings are welded with AZ92A rod, limit is 1/2 hr at temp.

(4) SO_2 atmosphere recommended for solution heat treating.

(5) Preheat usually needed on thin or restrained sections. Local or no preheat on heavy or unrestrained sections.

welding of thin sections and, in some cases, to the repair of castings. Its chief drawbacks are the low current-carrying capacity of the tungstens, shallow penetrations and wide beads. Helium gas is almost a necessity in d-c welding to maintain stable and sufficiently long arc. In the case of the a-c arcs, both helium and argon or mixtures of the two gases are used for shielding. Some prefer to use helium in place of argon in a-c welding because it increases the current carrying capacity of the tungsten, gives a slightly hotter arc with narrower and deeper weld penetration, and reduces the "arc popping" or "arc spatter" when operating at the top current-carrying capacity of a given size tungsten.

Tungsten-arc welding can be used on most all thicknesses. Backing bars are used wherever possible, although free drop-down can be readily used after some experience. Complete weld penetration is required for the maximum strengths. Rigid clamping to minimize distortion is necessary. In welding heavy thicknesses, little or no jigging is required if good tack-welding sequences are used. Single-pass square butt joints can be readily made in thicknesses up to 1/2 in. Welding speeds up to 16 ipm are possible manually, but the usual range is from 6 to 12 ipm.

Cleaning

As in other metals, cleanliness of all parts, including the welding rod, is important for sound welds. The presence of oil or organic material results in porous welds. Cleaning prior to welding may be done with mechanical means such as wire brushing or steel wooling. Chemical cleaning requires degreasing, followed by a chemical treatment of 2 to 3 min in a solution of 20% chromic acid plus 3% sodium nitrate solution, followed by rinsing and air drying. Weld "smoke" or the deposited surface oxide on the weld can be removed either by wire brushing or by chemically treating in a solution of 10% tetra sodium pyrophosphate plus 2% sodium metaborate at 180° F followed by a rinse and the required chemical treatment.

Completed welds may be inspected for soundness with the fluorescent or dye penetrants, X-ray and pressure tests. Chemical treatments often reveal cracks because of staining effects. For best quality welds in military applications, the operators must pass the MIL-T-5021 specification.

Consumable-Electrode Process[6]

This inert-gas-shielded metal-arc process features the use of a continuously-fed bare magnesium wire as the electrode and d-c electrode positive current as the power source. Argon gas is the preferred shield. Current densities up to ten times those in the tungsten arc are used. As a result, unusual effects on metal transfer are obtained. At low current densities, the metal transfer is globular and shallow penetration is obtained. As the current density increases, the globules decrease until a fine spray as shown in Fig. 9 is obtained, which also results in deep penetration. Welding speeds are in the range of 24

Table 12—Stress-Relief Treatments for Some Commercial Magnesium Alloys after Welding

Sheet			Extrusions			Castings*		
Alloy	Temperature, °F	Time, min	Alloy	Temperature, °F	Time, min	Alloy	Temperature, °F	Time, min
AZ31A-O	500	15	M1A-F	500	15	AZ63A	500	60
AZ31-H24	300	60	AZ31A-F	500	15	AZ92A	500	60
			AZ61A-F	500	15	AZ91C	500	60
			AZ80A-F	500	15	AZ81A	500	60
			AZ80A-T5	400	60	AM80A	500	60
			ZK60A-F	500	15	AM100A	500	60
			ZK60A-T5	300	60			

* Treatment applies to -F, -T4, -T5 and -T6 tempers.

Table 13—Welding Conditions for AZ61A Consumable Electrode on AZ31B Plate in Argon

Plate thickness, in.	*Wire diam, in.*	*Arc* — *Volts*	*Arc* — *Amp*	*Wire speed, ipm*	*Welding speed, ipm*	*Type of weld*
3/16–3/8	0.050	24–30	220–280	788–960	24–36	Butt and fillet
1/4	0.050	22–24	220–230	830–913	"	Vertical down fillet
1/2	0.050	24–26	220–230	913	"	Vertical down fillet
1/4	0.064	24–30	240–290	550–660	"	Butt and fillet
3/8	0.064	24–30	260–350	560–745	"	Butt and fillet
1/2	0.064	24–30	320–390	740–820	"	Butt and fillet
3/8	0.092	24–30	330–350	350–385	"	Butt and fillet
1/2	0.092	24–30	350–380	360–402	"	Butt and fillet
5/8	0.092	26–30	370–420	375–417	"	Butt and fillet
1	0.092	26–30	370–420	375–417	"	Butt

ipm = in. per min.

Table 14—Typical Shear Strengths of Spot Welds in AZ31B and HK31A Sheet

Sheet thickness, in.	*Average spot diam (in.)*	*Single spot shear strengths* — *AZ31B-O*	*HK31A-H42*
0.020	0.14	220	..
0.025	0.16	270	..
0.032	0.18	330	300
0.040	0.20	410	..
0.051	0.23	530	550
0.064	0.27	750	720
0.081	0.31	890	..
0.102	0.34	1180	..
0.125	0.38	1530	1420

to 36 ipm. The process can be used on materials 3/16 in. or thicker.

The deposition rates for the 0.027, 0.050, 0.064 and 0.092-in. diameter AZ61A wires in argon are shown in Fig. 10. Spray metal transfer, at which the best welding conditions exist, are obtained by operating above the critical current and wire speed indicated. The necessity for high melting rates results in considerably heavier than usual beads, with appearances as shown in Fig. 11. The best welding conditions to use with the different wires for the various metal thicknesses are summarized in Table 13. A comparison of the melting rates of AZ61A magnesium and 1100 (28) aluminum wires is shown in Fig. 12. The magnesium wire melts at least twice as fast as the same size aluminum for a given current. The high deposition rates should prove of considerable advantage in multi-pass welding.

Gas Welding

The gas-welding process, using an oxyacetylene flame and a chloride-base flux, is useful primarily for thin-gage stock. Its chief advantage over arc welding is the greater freedom in fit-up and the consequent simpler jigging. Wooden jigs can be used freely where the flame does not impinge on the wood. Its disadvantages compared to arc welding are the greater distortion, slower welding speeds, and dangers of flux entrapment and the resulting corrosion. Gas welding has been used only sparingly for magnesium in the USA since the advent of the inert-gas-shielded arc-welding process.

Spot Welding

The spot welding of magnesium requires good precleaning of surfaces for consistently sound welds. For the best welding conditions, surface cleanliness is usually indicated by a measure of the electrical surface resistance, which should be less than 50 microhms. Chemical cleaning is preferred to mechanical for most production work because faster and more uniform results are obtained. The chemical cleaner consists of a water solution of 18–24% CrO_2 and 0.05% H_2SO_4. Parts are immersed in this solution for 3 min after proper prior degreasing treatments.

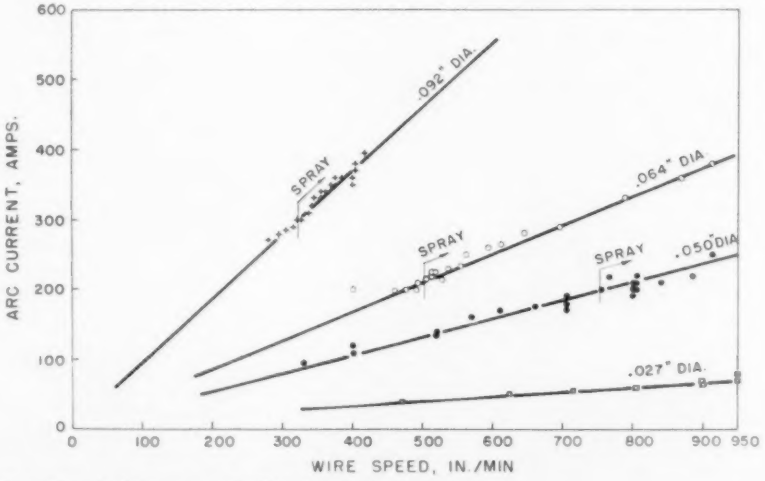


Fig. 10 Melting rates of AZ61A wire in argon arcs

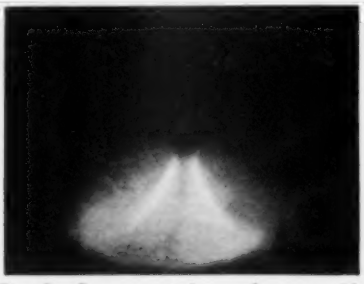


Fig. 9 Spray metal transfer arc with 0.064-in. diam. AZ61A wire in argon gas

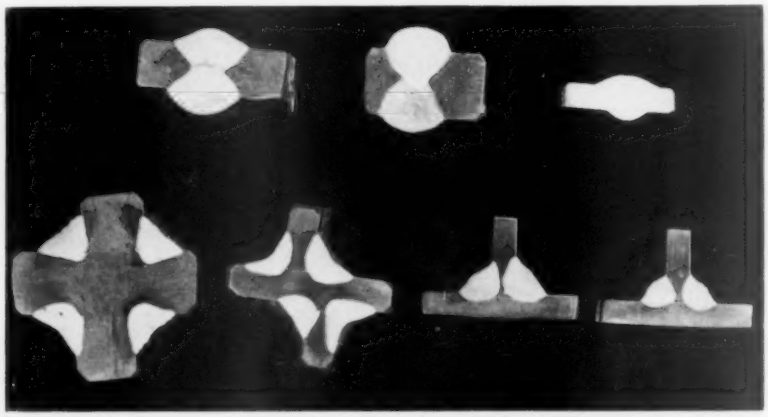


Fig. 11 Appearance of consumable-electrode welds in AZ31B-F plate

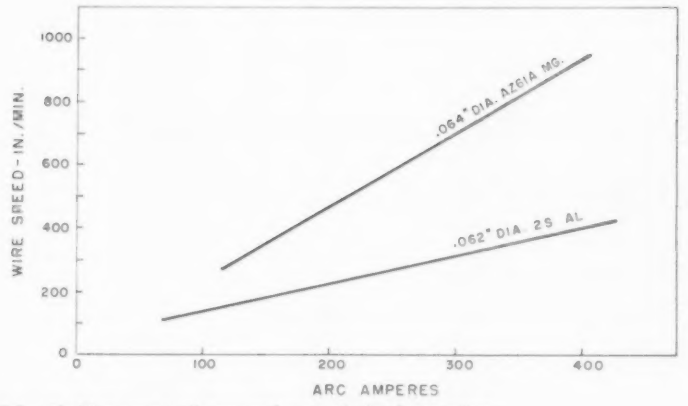


Fig. 12 Melting rates of magnesium and aluminum wires

The same welding equipment used for aluminum works satisfactorily on magnesium. The machines may be single-phase ac, the stored-energy type, or the latest 3-phase low-frequency type. In general, magnesium requires slightly lower currents and electrode forces than aluminum. Water-cooled high-conductivity-copper electrode tips are used. Tip radii are dome-shaped with radii ranging from 2 to 6 in. Under the best conditions, about 50 to 100 spots can be made between tip cleaning. Tip life is limited either by the appearance of copper on the surface of the spot or by sticking of the tips to the work piece. Copper deposits on magnesium are undesirable because of galvanic corrosion and should be completely removed with steel wool or fine abrasive.

Typical single shear strengths of welds in various gages are shown in Table 14. In general, spot-weld strengths are directly related to spot diameter and approximate strengths can be obtained from the spot diameters. Spot-welded joints have relatively low fatigue strengths in comparison with arc-welded joints and, therefore, should be avoided in applications where they might be subjected to excessive vibration.

Other Methods

Brazing, soldering, seam and flash-welding are not used widely at this time. Brazing applications using the flux-dipping technique have recently shown considerable promise.

Summary

The latest information on the metallurgy, static properties and welding characteristics of the commercial magnesium alloys currently used in the USA are presented. It is shown that the recently-developed high-temperature alloys containing rare-earth metals and thorium have good welding characteristics and weld strengths which approach or equal the strengths of the unwelded materials at elevated temperatures. The welding methods in widest use are shown to be the inert-gas-shielded tungsten-arc and resistance spot-welding processes. The characteristics and conditions for use of the new consumable-electrode inert-gas-shielded arc method are described. This method is characterized by high weld-metal deposition rates and deep penetration.

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APPENDIX

Compositions of Etchants for Magnesium Alloys

1.	Phospho-picral etchant	
	Orthophosphoric acid	0.7 ml
	Picric acid	4.0 g
	Ethyl alcohol (95%)	100 ml
2.	Acetic-picral etchant	
	Saturated picric acid in 95% ethyl alcohol	100 ml
	Glacial acetic acid	10 ml
3.	Acetic-glycol etchant	
	Ethylene glycol	60 ml
	Distilled water	19 ml
	Glacial acetic acid	20 ml
	Concentrated nitric acid	1 ml
4.	Glycol etchant	
	Ethylene glycol	75 ml
	Distilled water	24 ml
	Concentrated nitric acid	1 ml

Correction:

"Fundamental Concepts of Oxygen Cutting"
by R. L. Stoecker and W. B. Moen

In the March 1957 issue of THE WELDING JOURNAL, *page 155-s, center of column 3, the first equation reads as follows:*

$$Z = {}^1/_4 \pi n_a n_b (\sigma_a + \sigma_b)^2 \times \left[8\pi RT \, \frac{(M_a + M_b)}{M_a M_b} \right]$$

It should read:

$$Z = {}^1/_4 \pi n_a n_b (\sigma_a + \sigma_b)^2 \times \left[8\pi RT \, \frac{(M_a + M_b)}{M_a M_b} \right]^{1/2}$$

It is to be noted that the $^1/_2$ *power was omitted from the brackets in the original publication.*

The Editor

THE PRACTICAL WELDING METALLURGY OF NICKEL AND HIGH-NICKEL ALLOYS

Review of what is now known, or believed to be true, concerning the effect on weldability of some twenty elements which may be present in nickel-base alloys is given in IIW paper

BY GEORGE R. PEASE

ABSTRACT. The elements copper, chromium, iron and cobalt form binary solid solutions with nickel over wide concentration ranges and, within these ranges, have relatively little effect on its welding metallurgy. Another group of elements including sulfur, phosphorus, zirconium, boron and lead are practically insoluble and undergo eutectic reactions which can initiate hot cracking unless preventive measures are applied. In small amounts, aluminum, titanium, carbon, molybdenum and silicon are either beneficial or innocuous, but these elements, too, may induce hot cracking if their respective critical tolerances are ignored. Gas reactions may cause porosity if uninhibited, but cracking is usually not traceable to this source.

Introduction

Unlike iron, its near neighbor in the periodic table, nickel undergoes no phase transformation to complicate its metallurgy. For this and other reasons, one could assume the welding metallurgy of pure nickel to be so uncomplicated as to require relatively little discussion. The fact is however, that when nickel appears in commercially important forms, it is always alloyed with other elements. Even so-called commercially-pure nickel may contain up to $^1/_2\%$ of extraneous matter. Most high-nickel alloys contain at least 10% and up to 30 or 40% of other elements which have been added to modify its properties in some way.

Because these other elements are present and because they are present for commercially important reasons, it becomes desirable for the welding metallurgist to understand their individual and combined effects on weld metal and on those portions of the base metal which may be influenced by the heat of welding. To this end, it is proposed to review what is now known, or believed to be true, concerning the effect on weldability of some 20 elements which may be present in nickel-base alloys (Table 1). Experience and time will probably reveal exceptions to what are intended, for the purpose of this review, to be generalizations. This is as it should be and will represent progress whenever it occurs.

Table 1—Effects of Some Commonly Present Elements on the Weldability of Nickel and Nickel Alloys

Beneficial	*No major effect*	*Variable*	*Harmful*
Nb	Mn	Al	Pb
Mg	Cu	Ti	S
	Cr	C	P
	Fe	Mo	Zr
	Co	Si	B

Weldability of Nickel

One of the purest forms of nickel which is available in sufficient quantity for weldability studies is electrolytically deposited nickel. One might expect metal of this purity to be capable of being welded rather satisfactorily, but such is not the case. Irrespective of the filler metal which is used, extremely fine longitudinal cracks are likely to occur in the heat-affected zone of the electrodeposit, no further than 0.001 to 0.005 in. (0.02 to 0.1 mm) from the edge of the weld. The amount of cracking which is experienced decreases in logical fashion as the severity of induced welding stresses is decreased and for this reason, apparently, better results are obtained using the tungsten-arc process than by using consumable electrodes, either flux coated or inert-gas shielded. At the present time, a reasonable degree of immunity from this defect can be assured only by the most careful use of the tungsten-arc techniques.

This sensitivity to cracking could be interpreted as an indication that pure nickel, in itself, is not weldable. The available evidence seems to indicate, however, that the poor behavior of electrolytic nickel is attributable to the presence of traces of eutectic-forming impurities, probably sulfur but possibly oxygen or some other element or elements. Nickel of substantially greater purity has not been studied, but it probably should be.

So-called commercially-pure nickel, in either the rolled or cast forms, is weldable only by virtue of certain malleabilizing additions, the specific effects of which will be discussed in later paragraphs.

Major Alloying Additions

Copper, forming as it does, a complete series of solid solutions with nickel has comparatively little effect on its welding behavior. Metallurgically at least, the binary high-nickel alloys containing 15 to 40% of copper behave much like commercially-pure nickel when welded. The resistance of these alloys to diseasing, by extraneously introduced sulfur compounds, for instance, is changed only a little. Similarly, the need for alloying to control gaseous porosity is not significantly reduced by the presence of these amounts of copper and, in inert-gas welding practices at least, the control measures are approximately the same. Hot cracking of wrought nickel is usually not a problem either with or without copper present.

As the amount of copper increases further, and becomes the major element, the resulting alloys behave more like copper alloys than nickel alloys, but the presence of nickel is still manifest in the welding response of the alloy. Reduced amounts of the same

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Paper presented at the July 1, 1957 Meeting of International Institute of Welding, Essen, Germany.

deoxidizers that are used in the high-nickel-alloy weld deposits are used, for instance, to insure soundness in 70/30 and 90/10 copper-nickel weld deposits.

Chromium additions to nickel, within the range of present commercial importance, result in solid solution alloys, the binary diagram for which shows an attractively narrow freezing range. Empirical observations seem to support what the equilibrium diagram suggests, i.e., that chromium, in itself, is not detrimental, in any gross manner at least, to the freezing characteristics of alloy systems in which it is present. However, chromium-bearing alloys seem to be more susceptible than other high-nickel alloys to hot crack sensitivity when other elements, notably silicon, are present. The hot cracking susceptibility of a nickel-base alloy weld metal, for instance, with 15% of chromium, is sharply increased as the silicon content increases from a few tenths of a percent to 1% and higher, while levels of the order of 1% are relatively innocuous in nickel and nickel-copper alloys.

On the other hand, to offset this seeming disadvantage, chromium has a strong tendency to form stable oxides and nitrides, and this appears to be a distinct advantage from the standpoint of controlling gas porosity

Iron is frequently present in nickel alloys, in varying proportions, but, with a few exceptions, not for the purpose of enhancing the properties. Its presence is usually incidental, either because it was added as a ferro-alloy along with some other additive or, in the case of weld metal, because a joint was made which included an iron-base alloy as a second member. When steel is melted into a high-nickel alloy weld, there is some reason to believe that such residual elements as sulfur, phosphorus and, possibly, oxygen, which are normally present in more abundant quantities in steel than in nickel alloys, are more damaging to the properties of the weld than is the iron itself.

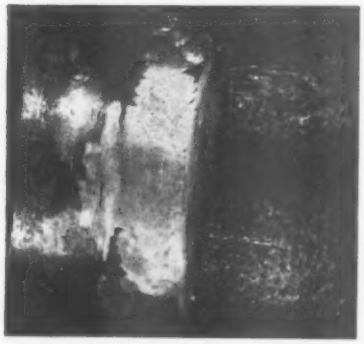

Fig. 1 Hot cracking in a nickel-chromium-iron weld caused by silicon pick-up from a 2% silicon stainless-steel casting. (One-half size)

In the specific case of nickel-30% copper alloy welds, the presence of up to 20 to 30% of iron appears to have no effect on welding response if the carbon content is held to levels of the order of 0.05 to 0.10%. At higher-carbon levels nickel-30% copper welds are crack sensitive, if diluted with more than a few percent of iron.

Cobalt at levels of the order of a few tenths of a percent can be considered to be without effect on weldability. At higher levels, as in the case of some of the new high-temperature alloys, there is insufficient data to develop any significant conclusions. It is probable, however, that the effects of cobalt will be found to be minor, except possibly as there are secondary effects, such as those of chromium, on the influence of other additives.

Molybdenum is one of the few major alloying additions which forms a second phase, and which is added in sufficient quantities in commercially important nickel alloys, to enter the two-phase area of the alloy system. Binary nickel-molybdenum alloys containing 20–30% of molybdenum are somewhat hot crack sensitive. While it cannot be demonstrated, perhaps, that the second phase is primarily responsible for the cracking difficulties, it seems reasonable to believe that it is contributory. Alloys containing molybdenum in the single-phase region appear to be considerably less crack sensitive.

Minor Alloying Additions

Carbon is usually present in wrought high-nickel alloys and nickel-base weld metals in amounts from 0.01% up to about 0.15 to 0.20%. Its effect on the welding behavior is variable, depending on what other elements are co-present. In wrought nickel, the carbon level is important to the welding behavior only if the anticipated service temperature falls in the range 600 to 1400° F (315 to 760° C). At these temperatures and below, the solubility of carbon is of the order of only 0.02 to 0.03%, but the solubility increases substantially with increasing temperatures. In the weld heat-affected zone, therefore, any graphitic carbon which may be present is dissolved, and is then held in supersaturated solution as the metal is rapidly cooled. Subsequent exposure in the temperature range indicated above permits the metastably held carbon to precipitate, which it does in the form of intergranular graphite. The microstructure is weakened thereby and local cracking or rupture may follow in service.

Unwelded high-carbon nickel plate or sheet can be similarly embrittled at these temperatures, presumably by diffusion of carbon to the grain boundaries, but as would be expected,

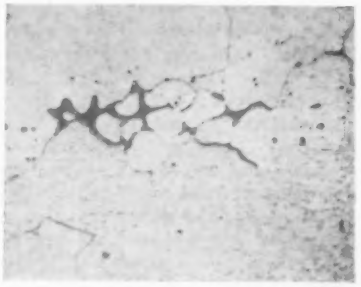

Fig. 2 Low-melting-point phase in the heat-affected zone of a wrought 0.25% zirconium-nickel alloy weldment. Etchant: Cyanide-persulfate. X 1000 (Reduced by one-third upon reproduction)

longer times are required than in the case of weld heat-affected metal. Whether welding is involved or not, the remedy is to limit the carbon level of wrought nickel to something of the order of 0.02% maximum or, in some cases, to add carbide-forming stabilizers. In the case of weld metal, titanium is usually present for the primary purpose of gas fixation in sufficient quantity to serve the secondary purpose of forming thermally-stable titanium carbides.

In copper-nickel alloys, the presence of copper alters the high-temperature solubility of carbon to the point where graphitic embrittlement is not encountered. Up to 0.15–0.20% at least, the carbon content of copper-bearing nickel alloys is relatively unimportant to its welding metallurgy. An exception is the case of weld metal, when it becomes diluted with iron. Here, if the carbon level is not held below about 0.10%, weld hot cracking may result, particularly if the joint is severely restrained during welding.

In chromium-bearing high-nickel alloys, carbon is present as chromium carbide. Titanium or niobium* carbides are formed preferentially, if these elements are present, but, in most cases, stabilization with these elements is not necessary to insure adequate corrosion resistance. Chromium depletion may occur in the heat-affected zone, as it does in iron-base alloys, in the absence of titanium or niobium, but only in the presence of particularly aggressive corrosive media does this result in impairment of the corrosion resistance. Niobium is frequently present in chromium-bearing high-nickel-alloy weld-metal compositions, in carbon-stabilizing proportions, but not primarily for that purpose. Its primary function, that of controlling harmful silicon effects, will be described in later paragraphs.

* Usually referred to as "Columbium" in American literature.

Manganese is frequently present in both weld metal and wrought compositions in amounts up to about 1%, but its effect on welding behavior in this concentration range can be ignored for all practical purposes. Even larger amounts, up to about 4%, have comparatively little effect. A possible exception is the case of nickel-chromium-iron weld-metal compositions containing 25% or so of iron, where a little improvement in resistance to weld hot cracking can sometimes be attributed to the presence of manganese.

Magnesium is important to the metallurgy of nickel and its alloys but full advantage of its usefulness cannot be realized in welding because of its fugitive nature when it crosses the welding arc. Its function in wrought products is to form stable, high-melting-point magnesium sulfides preferentially to the extremely low-melting-point nickel-nickel sulfide eutectic. Its contribution can be compared to that of manganese in steel metallurgy. In the amounts which are added to wrought high-nickel alloys to impart hot malleability, magnesium also serves to prevent hot cracking in the heat-affected zone.

In metal-arc welding with covered electrodes, the losses of magnesium by oxidation and/or volatilization are so great that, with a few exceptions, no more than ineffectively small amounts of magnesium are recovered. Under these circumstances, control of sulfur, where necessary, is dependent upon the presence of such other elements as niobium, titanium and aluminum, recoveries of which are substantially better than the recovery of magnesium.

In the inert-gas metal-arc welding processes, using either consumable or nonconsumable electrodes, and in the oxyacetylene welding process, magnesium recoveries are better than they usually are in covered-electrode welding. In these cases, therefore, sulfur fixation is quite readily accomplished with magnesium.

Silicon is present in commercially pure nickel and in nickel alloys in amounts varying from about 0.1 to 4% or more. In most alloys, its effect on weldability is rather consistently subversive, with a strong tendency to induce weld hot cracking. The threshold for damage varies considerably, however, from alloy to alloy and from one welding process to another and it is more potently damaging in weld metal than in the heat-affected zone of the base metal. Its solubility in pure nickel is sufficiently high, in the absence of other alloying additions, to preclude the possibility of sufficient eutectic melting to initiate hot cracking, but this solubility is apparently reduced with additions of chromium and/or copper.

In copper-nickel alloys containing about 30% copper, for instance, silicon begins to increase the weld hot crack sensitivity at levels of the order of 1%, in metal-arc welding, and at perhaps twice that level in oxyacetylene welding. As the copper content increases, the tolerance for silicon is further reduced.

Silicon is particularly damaging to the hot crack resistance of chromium-bearing high-nickel alloys. In metal-arc weld deposits, as little as a few tenths of 1% contributes grossly to the hot crack sensitivity. In oxyacetylene welding the tolerance is somewhat greater.

In depositing weld metal on high-silicon-content base metal, cracking difficulties are more likely to be the result of silicon pick-up in the weld metal (Fig. 1) than from cracking in the heat-affected zone.

Niobium is added to high-nickel alloys to counteract the damaging effects of silicon, particularly in nickel-chromium-iron weld metal, deposited by the covered-electrode process. The amount of niobium required to prevent hot cracking varies with the nickel/iron ratio, from a low of about 4.5 times the silicon content in a 75% nickel, 15% chromium, 7% iron alloy to a high of about 8 or 9 times the silicon content in alloys containing 35% nickel, 15% chromium and 50% iron. Similar relationships appear to exist in the case of welds made under inert gas, but metal deposited by the oxyacetylene process does not usually require this control.

Irrespective of the alloy composition, the threshold level for silicon-induced damage appears to be considerably higher in the heat-affected zone than it is in the deposited metal. Unless the silicon content is unusually high, therefore, as in cast compositions, niobium additions are not required to control silicon effects in the heat-affected zone of even the relatively sensitive nickel-chromium-iron alloys.

Zirconium additions to nickel of a few tenths of 1% result in a two-phase alloy which is extremely hot crack sensitive. A eutectic reaction (Fig. 2) appears to occur at about 2000 to 2100° F (1090 to 1150° C) which causes severe cracking in the heat-affected zone. Weld metal is even more crack sensitive than the heat-affected zone. Although generous additions of zirconium-free filler metal are capable of diluting the zirconium effect and producing a reasonably crack-resistant weld metal, the sensitivity of the heat-affected zone makes it necessary to classify zirconium-nickel alloys as nonweldable by fusion welding, until such time as a satisfactory antidote is discovered.

Aluminum is a useful addition to high-nickel alloys, being used at different levels, as (1) a deoxidizer and (2) as an age-hardening constituent. When the addition is substantial, hot crack sensitivity is increased, with the threshold level dependent, like that of silicon, upon what other elements are co-present and, of course, the amount of stress to which the weld is exposed as it solidifies and cools. The tolerance for aluminum is much greater in the heat-affected zone than in the weld metal and in most cases the tolerance is greater in the weld metal than the tolerance for silicon under similar circumstances.

The very useful contribution which aluminum imparts to the age-hardening response of high-nickel alloys makes it a desirable addition to filler wires for welding the age-hardenable nickel alloys. In most cases, however, the threshold for initiation of hot cracking is reached before the maximum aging

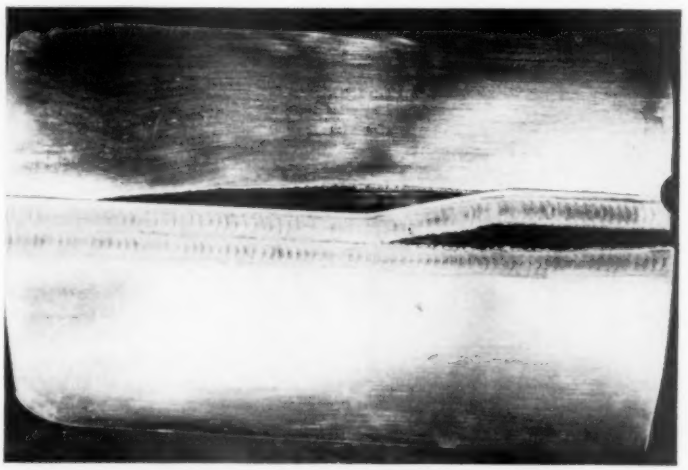

Fig. 3 Brittle failure of a seam-welded lap joint in 15% copper-nickel alloy contaminated with sulfur. (Two-fifths actual size)

response can be developed. Supplementary additions or substitutes are necessary, therefore, in filler-wire compositions if the base-metal properties are to be fully matched.

In some weld-metal compositions, aluminum seems to have a beneficial effect on weld soundness, but the effect is not as potent as that of titanium.

Titanium additions are frequently made to high-nickel-alloy weld-metal compositions, particularly chromium-free compositions, for the purpose of insuring freedom from gas porosity. As mentioned earlier, chromium, in itself, seems to possess substantial gas-fixing properties, which decrease the dependence upon supplementary additions of titanium in chromium-bearing alloys.

Titanium is also frequently added, along with aluminum, to develop an age-hardening response and its effect on the welding behavior is much like, and additive to, that of aluminum. At certain critical levels, the weld metal becomes hot short, and crack-free welds become difficult to obtain in highly restrained joints. In the case of some of the stronger high-temperature alloys, direct solutions to the problem of matching the base-metal properties with adequate weld-metal properties are not yet in sight but recourse to expedients, such as weld reinforcement and the strategic location of welded joints in cooler areas, is being used to good advantage. The permissible level for aluminum plus titanium appears to be greater for the tungsten-arc process than for the consumable-electrode process. Until other age-hardening weld-metal systems are developed, therefore, the preferred use of the tungsten-arc welding method is indicated as a further means of bettering the welding response of the age-hardenable alloys.

The tolerance for aluminum and titanium in the heat-affected zone is considerably greater than the tolerance in weld metal and is usually not a problem from the standpoint of hot cracking during welding.

Boron has been added to certain of the high-temperature nickel-base alloys, in the range 0.03 to 0.10%, for the purpose of improving the high-temperature mechanical properties. The practical usefulness of boron is reduced, however, by its grossly damaging effect on weldability. Weld metal with these amounts of boron is extremely hot crack sensitive. The heat-affected zone is likewise subject to hot cracking unless considerable care is excercised with respect to heat input and stress levels, and other welding variables. Less than about 0.03% boron is not usually damaging in the heat-affected zone but the sensitivity to weld damage persists even below this level, with the permissible amount varying with the welding conditions and alloy composition. The effect appears to be one of grain boundary liquation, similar to that of other elements such as sulfur, phosphorus and zirconium, all of which form a low-melting-point eutectic composition with nickel.

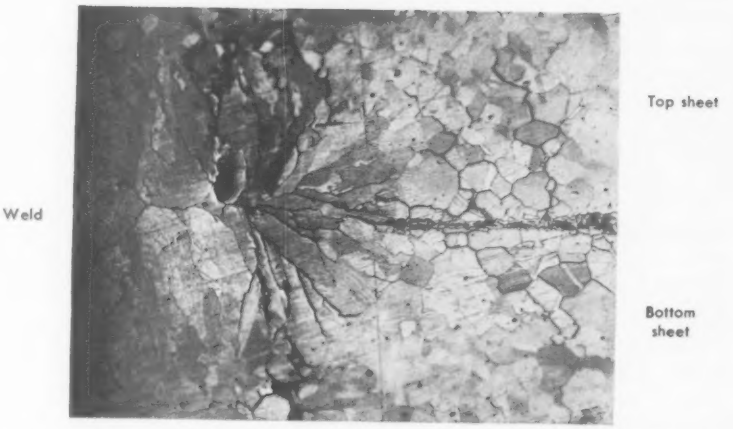

Fig. 4 Intergranular cracking of weld and heat-affected zone of sulfur-embrittled joint shown in Fig. 3

A portion of the sulfur-rich eutectic has been extruded into the gap between the faying surfaces. X 50. Etchant: Cyanide-persulfate.

Other Elements

Sulfur is probably the most subversive of all of the elements which are involved in the welding metallurgy of nickel and the high-nickel alloys. In many cases, control of this one element can make the difference between successful and unsuccessful welded fabrication. Sulfur is damaging to nickel because of its extremely limited solid solubility, coupled with a nickel-nickel sulfide eutectic reaction which takes place at 1200° F (650° C), the lowest of the several eutectic reaction temperatures in which nickel is recognized as a reactant. In most high-nickel alloys, there is enough residual sulfur to exceed the solubility limit, but if the alloy is properly made, a sufficient quantity of magnesium or other sulfur-fixing elements will have been added to inhibit the eutectic reaction with nickel, in both the weld metal and in the fusion zone. Unless these elements are consumed in the welding process, therefore, there should be no difficulty from this source.

In practice, however, sulfur and sulfur compounds are so ubiquitous that unusual diligence is required to insure that welds and weld heat-affected zones are not enriched with sulfur, from extraneous sources, to the point where the corrective additions are no longer effective. It is possible, for instance, to pick up enough sulfur from such materials as marking crayon, cutting lubricants and other foreign matter to exceed the normal capacity to fix sulfur and thereby induce brittleness via the formation of intergranular sulfide films.

In the case of most of the elements which adversely affect the weldability of nickel, and particularly in the case of extraneously introduced elements, the weld metal is more likely to be damaged than the heat-affected zone. With sulfur, however, the heat-affected zone is almost equally susceptible. The mechanism is not well understood but something more profound appears to be involved than the simple 1200° F (650° C) eutectic reaction. In any event, the net result is a penetration of the grain boundaries in any portion of the weld heat-affected zone which is heated above the threshold temperature for that alloy, while in contact with any sulfur-bearing material. The threshold temperature for this type of embrittlement varies from about 600° F (315° C) for pure nickel to about 1200° F (650° C) for chromium-bearing alloys. To illustrate the magnitude of this effect, Figs. 3 and 4 show an extreme case where nickel-copper alloy sheet, 0.050 in. (1.3 mm) thick, became embrittled by this so-called sulfidation mechanism throughout the entire cross section, during a seam-welding operation. In this particular case, the amount of contamination was so great that the embrittling phase was clearly evident in the microstructure but, usually, evidence of a second phase is difficult to detect, metallographically. The offending surface contaminant was never positively identified, but was probably nothing more uncommon than a combination of machining lubricant and shop dirt.

Lead causes hot shortness in high-nickel alloy weld metal at about the same level as sulfur does. In practice, however, much less weld cracking is experienced from lead than from sulfur, but probably only because it is less abundantly present than sulfur in

materials which are likely to be present as a contaminant.

Useful phase diagrams are not available for the nickel-lead system, but the metallurgical explanation of the subversive effect of lead is probably very little different than that of the sulfur effect. It can be assumed that, because of a very limited solid solubility, lead or a lead-rich low-melting-point grain-boundary material is rejected as the matrix freezes, with cracks occurring through the rejected liquid.

Barring the possibility of careless melting practice such as, for instance, the production of casting compositions in a furnace or a crucible which has been used to melt leaded bronzes, the lead content of nickel alloys is normally sufficiently low so that cracking in the heat-affected zone is not a problem. Surface contamination by lead has been suspected in certain cases of embrittlement in the heat-affected zone of wrought nickel alloys, but lead effects are neither as potent nor as frequently encountered as sulfur effects.

Phosphorus only infrequently becomes involved in the welding metallurgy of nickel and the high-nickel alloys, but when it does, its effect on weld metal is very similar to that of lead and sulfur. Its solubility in nickel, like that of lead and sulfur, is quite limited and it undergoes a eutectic reaction at about 1600° F (870° C). Severe weld hot cracking has been traced to the presence of as little as a few hundredths of a percent of phosphorus. There is no evidence, however, which would suggest that phosphates or other phosphorus-containing contaminants are likely to embrittle the heat-affected zone, as do contaminants containing lead or sulfur.

Gaseous elements such as oxygen, nitrogen and hydrogen are important to the welding response of high-nickel alloys, but only from the standpoint of weld-metal porosity. Cracking seldom if ever can be traced to the presence of dissolved gases, either in the weld metal or in the heat-affected zone. Coating formulations with closely controlled hydrogen contents are unnecessary, for instance, as they are for welding hardenable steel. The addition of suitable gas fixing elements, notably titanium and aluminum, to the fusion is sufficient to eliminate any harmful effects of dissolved gases.

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REVIEW OF RUSSIAN WELDING ARTICLES

BY G. E. CLAUSSEN

The No. 5 issue of the Russian magazine *Automatic Welding* for 1956, published by the Paton Institute of Electric Welding in Kiev, contains the following articles:

1. "Automatic Electric Arc Welding of Titanium," by S. M. Gurevitch and S. V. Mishenko, pages 1–12. Welding conditions are given for welding commercial titanium with thoriated-tungsten electrode and argon. Submerged-arc welding is described using a flux containing no oxygen and commercial titanium electrode, 175 to 320 amp.

2. "Welding 18–8 Stainless Steel 1/8-In. Thick with Carbon-Dioxide Shielding Gas," by A. G. Potaievsky, pages 13–18. There was a small loss of chromium and over 50% loss of titanium in welding Type 321 steel with Type 321 electrodes. Mechanical properties were good.

3. "Welding Alloy Steels with Carbon-Dioxide Shielding Gas," by B. S. Kasatkin, N. I. Kakhovsky and Iu. N. Vakhnin, pages 19–21. The effect of titanium in the electrode on recovery of Si, Mn, Cr and Mo is shown for a 1% Cr, 1/2% Mo steel. A powder metallurgy electrode containing 1.5% Ti reduced spatter and produced weld metal containing a little more oxygen but less nitrogen than welds made with covered electrodes.

4. "Edge Welding Two Steel Strips Which Are Expanded by Internal Pressure to Form Pipe," by G. V. Raevsky, pages 22–30.

5. "Electric Butt Pressure Welding of 0.6% Carbon Steel," by A. V. Obukhov and V. B. Shlyapin, pages 31–36. Reheating in the machine to 1000–1100° C improved the mechanical properties.

6. "Tests on the Flexibility of Welded Plate Girders at −50° C of Plain Carbon and 1% Cu. 1/2% Ni Steels," by V. I. Novikov and V. V. Shevernitsky, pages 37–42.

7. "Sigma Phase in Fully Austenitic Welds in Type 310 Austenitic Steel," by B. I. Medovar, pages 43–60. Sigma forms more or less rapidly at 1290° to 1560° F. Heating for 2 to 4 hr at 1830° F dissolves the sigma phase and restores ductility.

8. "Static and Impact Strength of Welded Girders at Room Temperature and −67° C," by V. Iu. Shishkin, Lu D. Guzevitch and R. Z. Manilova, pages 61–65.

9. "Raising the Quality of Large Diameter Welded Gas and Oil Pipes," by S. L. Mandelberg, pages 66–72. Two, three and four electrodes are used in welding the longitudinal seams by submerged-arc process at 50 ipm.

10. "Spectrographic Analysis of 80 Ni–20 Cr Welds," by E. S. Kudelya, pages 73–79.

11. "Rapid Methods for Analyzing Submerged-Arc Flux AN 348A," by N. A. Longer and T. P. Novikov, pages 80–83.

12. "Ultrasonic Inspection of Tee Fillet Welds," by A. K. Gurvitch, pages 84–89.

13. "The Effect of Residual Stresses in Reducing the Fatigue Strength of Welded Joints," by V. I. Trufyakov, pages 90–103.

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ARC WELDING OF VACUUM- AND INERT-ATMOSPHERE-MELTED ZIRCALOY-2

Significant difference in the anode heat output is found to exist with Zircaloy-2 materials, and is attributed to the presence of certain impurities

BY HOWARD C. LUDWIG

ABSTRACT. The differences found in penetration when arc welding zirconium sponge-base alloys, melted by two melting processes, have been attributed to a variance in anode heat output as determined from calorimetric measurements. Indications are that the variance in anode heat output is due to the diffusion and evaporation of chlorine and hydrogen from the arc-melted anode surface. These gases are present in the zirconium alloys as residuals whose source is the zirconium sponge. A mechanism by which the gases increase the anode heat output is described.

Introduction

A variance in the welding of zirconium sponge-base alloys has been attributed to minor variations in their resultant chemical compositions (Table 1) which are characteristic of the alloy melting process methods. It is reported that variations by a factor of 10 in weld penetration and size of molten pool have been observed between Zircaloy-2 ingots almost indistinguishable in chemical analysis.[1] Zircaloy-2 is made by two process methods: (1) vacuum arc melting with a consumable electrode,[2] and (2) inert-gas arc melting with a consumable electrode.[3] In the welding operation, a 99.999% pure helium shielded arc is employed between a pure tungsten or thoriated-tungsten cathode and the Zircaloy-2 workpiece anode. Evidences of a possible variation in the arc energy distribution are indicated by the necessity to increase the welding current when changing from a Zircaloy-2 workpiece of the inert gas to one of the vacuum-melting practice. Besides entailing extra production time in the handling of two production specifications, an increase in current does not rectify the problem because the significantly large difference in arc penetration requires excessively large nonconsumable electrodes to carry the higher welding currents. The variation in arc penetration for Zircaloy-2 workpieces from the two melting practices is shown in the graph of Fig. 1.

The marked difference in the weld penetration is shown by the photographs of Fig. 2. The top and bottom sides of weld beads, made on representative Zircaloy-2 workpieces, are shown. The right and left parts of the bottom views show the differences in depth of penetration. Little or no melt-through is indicated, at a current in the range of 125–200 amp, for vacuum-melted Zircaloy-2, while melt-through is readily observable beginning at 150 amp in the case of the atmosphere-melted Zircaloy-2.

To determine whether the arc energy distribution was different with respect to the sponge-base-alloy melting process employed, a calorimetric system of experimentation was designed. By calorimetry, the cathode and anode heat outputs which would serve to compare the Zircaloy-2 anode materials can be measured. From a quantitative study, it was believed that the source of the weld penetration variance could be found.

Before describing the arc energy distribution with regard to the heat balance determinations, it is appropriate to consider the theory of the high-pressure arc and reasoning which substantiates the calorimetric method of approach to the problem.

High-Pressure Arc Theory

The welding arc consists of a column of electrically and thermally excited gas which conducts current of a few to several hundred amperes through a potential drop of usually tens of volts. The gas temperature varies with the electrode materials and kind of gas; it was reported to be about 6000° K at atmospheric pressure for iron welding arcs.[4] At this very high temperature, the gases and vaporized electrode materials are ionized so that the neutral atoms are broken up to usually form positive ions and electrons. In the

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Table 1—Chemical Composition (Parts per Million) of Representative Zircaloy-2 Materials

Ingot number	*Sponge blend*	*N*	*C*	*Cl*	*H*	*O*	*Al*	*Co*	*Cu*	*Hf*	*Mg*	*Mn*	*Mo*	*Pb*	*Si*	*Ti*	*V*	*W*	*B*	*Cd*
5Y679*	Q-63	39	55	32	58.6	1400	37	<10	5	<100	1	30	<10	9	9	<20	<10	<50	<0.2	<0.2
FZ09†	Q-64	37	90	6	18	1500	44	<10	17	55	4	21	<10	<10	<50	<20	...	<50	...	...

	Sn	*Fe*	*Ni*	*Cr*
Nominal alloy composition of Zircaloy-2	14500	1350	550	1000

* Inert-gas-arc melt.
† Vacuum-arc melt.

presence of the electric field, electrons are drawn from the cathode and move towards the anode. The positive ions originating at the anode move toward the cathode. Due to their smaller mass, the electrons are of a higher energy state and have higher velocities. The more energetic electrons experience more collisions with neutral atoms to ionize them and maintain the temperature of the arc. Due to space charges which occur at locations near the electrodes, the potential gradient along the axis of the arc is not uniform but varies in the three regions known as the anode fall, positive column and cathode fall. The first and last regions are extremely short in length but represent the largest gradients in the total potential. The total potential is the sum of all three potential regions. If the arc length were to be reduced to zero, the total potential (V) would be the sum of the anode and cathode potential drops according to the following equation:

$$V_{\text{total}} = V_{\text{anode}} + V_{\text{cathode}} \quad (1)$$

The theoretical arc-heat energy balance is essentially governed by the conducted current and the voltage drops in the three regions of the arc. In determining the voltage drops, one must take into account the heat losses and transfer from each region. In addition, the calculation of the anode and cathode voltage drops requires experimental data on the plasma gradient and the relation between the anode and cathode heat output with arc length. With these data, extrapolation to zero arc length makes it possible to eliminate the positive column voltage-drop variable in determining the anode and cathode drops.

It is now necessary to describe the heat balance in the anode and cathode regions. It will be assumed that axial and radial losses in the arc column are very small due to the short arc lengths involved. This assumption is substantiated by Ornstein[5] who has shown that a type of high-pressure arc had a constant temperature along its axis, and Suits[4] measurements show that the radial temperature gradient is zero within narrow limits.

There are two main sources of heat loss from the cathode region: firstly, the cooling effect of electrons removed from the tungsten-metal surface and secondly, the heat loss to the environment through the electrode by metal-vapor transfer, radiation and conduction. Conduction losses appear to be the most substantial. The metal-vapor loss is not very high because of the refractory electrode. The cooling effect of the electrons is subdivided as follows: losses attributed to the work done on each electron are equal to ϕ_c, the work function of the cathode metal surface. The rate of heat loss due to this source in watts is $\phi_c I$, where I is the current conducted. Secondly, losses occur due to the flow of electrons to the anode. This loss, determined from kinetic theory, is $2kT$ per electron, which at 6000° K, a measured gas temperature of a high-pressure iron arc,[4] is about 1 volt. The (k) is Boltzmann's constant. The losses due to this source in watts would be I x 1 volt. The total losses for the cathode are therefore:

$\phi_c I + \dfrac{2kT\,I}{e} + Q_{c_o}$, where Q_{c_o} = cathode heat loss at zero arc length. The expression must be equal to $V_c I$; where V_c = voltage drop at cathode

$$V_c I = \phi_c I + \frac{2kt}{e} I + Q_{c_o} \quad (2)$$

or

$$V_c = \phi_c + \frac{2kT}{e} + \frac{Q_{c_o}}{I} \quad (2a)$$

Since the cathode of the arc contributes to the heat dissipated at the anode by the flow of electrons $2kTI/e$, the anode heat-balance equation must include this quantity in the calculation of the anode drop (V_a), so that where Q_{a_o} = heat dissipated in the anode at zero arc length, and ϕ_a = anode work function:

$$Q_{a_o} = V_a I + \phi_a I + \frac{2kT}{e} I \quad (3)$$

or

$$V_a = \frac{Q_{a_o}}{I} - \left(\phi_a + \frac{2kT}{e}\right)$$

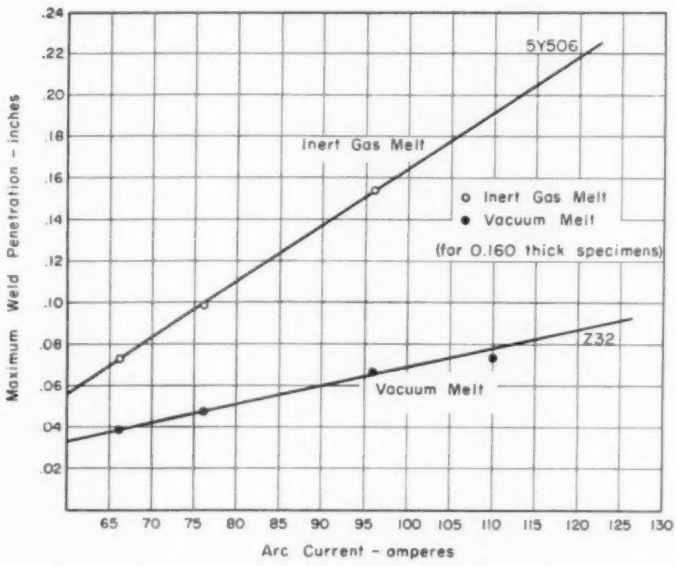

Fig. 1 The variation of weld penetration with current for Zircaloy-2 material

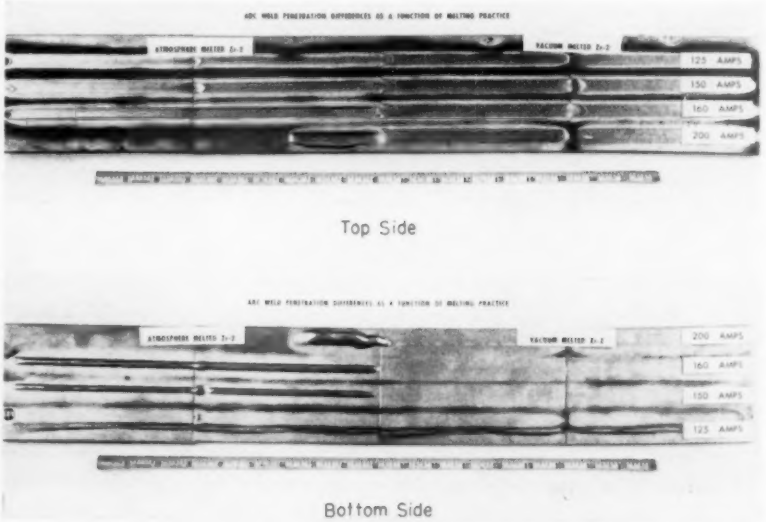

Fig. 2 Arc weld penetration as a function of melting practice

The anode work function is defined as the energy required to remove positive ions from the anode. The arc theory described only roughly represents the anode and cathode characteristics of the high-pressure arc, however, it includes substantially the major heat losses involved. The theoretical considerations of the above are principally contributions of Cobine[6] and Lancaster[7] and also of many others who have studied the physics of the arc.

The Design of Experiment

It was from the aforedescribed heat-balance equations that the plan of experiment was based. With known work functions of cathode electrodes one can determine the cathode and anode voltage drops from the experimentally determined plasma gradients and heat losses. The cathode voltage drop is determined from the heat loss data extrapolated to zero arc length; Equation (2a), where, in the case of a pure tungsten electrode,[8] $\phi_c = 4.52V$. The value $2kT/e$ is calculated from Kinetic Theory and is equal to 1 volt.

Fig. 3 Complete calorimetric apparatus

The anode drop at zero arc length is determined from Equation 1:

$$V_{to} = V_{co} + V_{ao} \qquad (1a)$$

where V_{to} is determined from the plasma gradient data and V_{co} from Equation (2a).

The sum of the anode and cathode drops, being equal to the total voltage drop at zero arc length, is also equal to the quantity $Q_{co}/I + Q_{ao}/I$, and

$$V_{to} = V_{co} + V_{ao} = \left(\frac{Q_{co}}{I} + \frac{Q_{ao}}{I}\right) \qquad (1b)$$

An experimental determination of the sum of the bracketed quantity from the anode and cathode heat losses should equal the experimentally determined V_{to} (total voltage drop at zero arc length). If the cathode heat loss (output) is the same for both materials the corresponding anode drops can be determined. The higher anode voltage drop gives a greater anode heat output. A difference in the anode voltage drops for the two Zircaloy-2 materials might indicate that some impurity in one of them was influencing the anode space charge.

The Arc Calorimetric Equipment

The design of the arc calorimeter was dictated by the requirement of a practical method for which heat could be transferred to a heat absorbing medium (water) separately from the anode and cathode terminals of the arc. Flow calorimetry lends itself well to this type of application. For measuring the heat developed per unit time by an object, it is necessary to know: (1) the difference, Δt, between the temperatures of the water leaving and entering the calorimeter; and (2) the volume of water, V, passing per unit time through the calorimeter. If the object is developing a constant amount of heat per unit time through the calorimeter the equation applied is:

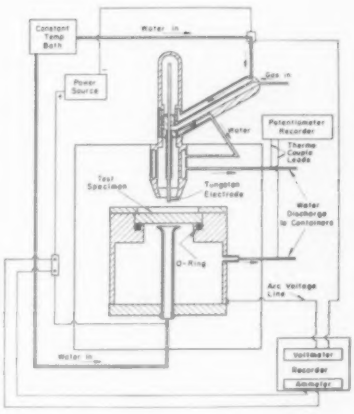

Fig. 4 Flow calorimeter

$$\Delta Q = V \cdot D \cdot C \cdot \Delta t \qquad (4)$$

where ΔQ is the heat developed and V is flow rate of water through the calorimeter; C is the specific heat of the water, D is the density of the water, and Δt is the difference in the temperatures of the water entering and leaving the calorimeter. The energy equivalents of objects and the apparatus are not taken into consideration in flow calorimetry. The difference in water temperatures is determined after thermal equilibrium has been reached for each terminal half of the calorimeter. The calorimeter parts are continually being cooled by the incoming cooling water.

The parts of the calorimeter are shown in Fig. 3 and schematically in Fig. 4. The constant temperature water (24° C) flows by siphon from the reservoir to the anode and cathode portions of the calorimeter. Iron-constantan thermocouples were inserted into the outlet tubes of each calorimeter part.

Table 2—Calorimetric Data Anode and Cathode Heat Output

Test no.	Indentification no.	Arc length, in.	Arc voltage current Volts	Amp	Power, Watts	Water flow rate, ml/sec Cathode	Anode	Temperature rise, ° C Cathode	Anode	Heat output, cal/sec Cathode	Anode	Heat output, watts Cathode	Anode	Heat output watts/amp Cathode	Anode
1	FZ99	0.025	14.8	60	888	4.48	10.65	8.0	15.0	36.0	160	150	667	2.50	11.10
2	FZ99	0.049	16.3	59	959	3.58	5.22	7.8	31.4	27.9	164	117	685	1.99	11.60
3	FZ99	0.095	19.1	60	1146	4.32	7.23	11.0	27.0	47.5	195	199	817	3.32	13.60
4	FZ99	0.103	19.7	60	1182	4.32	10.33	10.5	20.3	44.8	208	192	830	3.20	13.83
5	FZ99	0.253	28.5	59	1682	3.95	10.22	25.0	24.0	98.8	245	413	1025	6.98	17.35
6	5Y679	0.030	15.5	62	961	4.33	5.24	9.0	38.5	39.0	202	163	845	2.63	13.62
7	5Y679	0.047	16.5	59	974	3.90	5.70	7.5	34.0	29.3	194	123	812	2.08	13.75
8	5Y309	0.049	16.8	59	988	3.82	5.38	9.0	38.2	34.4	206	144	862	2.44	14.60
9	5Y679	0.075	18.3	60	1098	3.68	6.85	13.5	29.5	49.6	202	208	845	3.47	14.10
10	5Y679	0.093	19.5	60	1170	4.26	6.70	13.0	35.0	55.3	232	232	979	3.87	16.32
11†	5Y679	0.024	15.3	60	918	4.34	9.77	9.5	16.5	41.3	162	171	675	2.85	11.50
12†	5Y679	0.065	18.0	60	1080	4.35	10.10	10.5	18.0	45.6	183	182	765	3.03	12.75
3A*†	FZ99	...	15.3	60	915	4.47	7.25	7.5	23.0	33.5	167	140	697	2.33	11.63
4A*†	FZ99	...	14.3	60	858	4.39	6.95	6.0	23.0	26.4	160	110	669	1.83	11.15

* Iodine introduced.
† Not included in graph of Fig. 5.

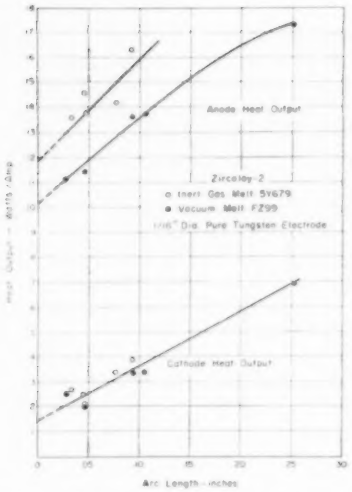

Fig. 5 The variation of cathode and anode outputs with arc length (arc current, 60 amp)

The water output temperatures were recorded versus time on a two-point potentiometer-recorder. The cathode calorimeter was a modified tungsten welding torch as shown schematically in Fig. 4. The anode calorimeter was designed to accommodate the Zircaloy-2 specimens which were machined to a disk form (1.45-in. diam x 0.238-in. thick). As shown in Fig. 4, the cooling water impinges against the underside of the specimen, the water being sealed off by means of an O-ring assembly.

Experimental Procedure

Before making a run, the electrode was conditioned by arcing at the appropriate current in a helium atmosphere to form a stable bead at the tungsten tip to eliminate errors in measuring the arc length. A Zircaloy-2 specimen representing the inert-gas-melting or vacuum-melting practice, previously cleaned by etching in a hydrofluoric acid solution, was assembled and the anode calorimeter brought into position concentrically below the nozzle. The gas-shielding nozzle was brought to a distance of $^1/_{16}$ in. from the anode calorimeter. This spacing provided room for the helium-shielding gas to escape.

To begin a run, the water flow was started and the time recorded. When the water temperatures had reached equilibrium, the arc was struck by impressing a high-voltage, high-frequency spark between the electrode and anode and the arc allowed to run until thermal equilibrium was reached as indicated by the temperature-time record. The high-frequency spark was shut off upon the initiation of the arc. The arc was stopped and the water was permitted to flow until the initial temperature was again reached. The water flow was stopped and the time recorded. Running records of total arc voltage and current were obtained for each test.

Data were obtained for only one current value (60 amp) which, according to the preliminary information, was enough to show evidence of the difference in welding of the specimens of the subject melting practices. The power supply was a 300 amp rectifier type d-c welder.

Experimental Results

The results compiled in Table 2 and Fig. 5 definitely indicate the difference in the anode heat output of the two Zircaloy-2 materials. As shown by the curve of Fig. 5, the anode heat output for the inert-gas melt Zircaloy-2 is higher for all variations in arc length. However, an anomalous condition was found in all cases of the vacuum-melt Zircaloy-2. A complete heat balance was not obtained, being as great as 18% less than the input. With the inert-gas melt Zircaloy-2, a complete heat balance was obtained except in some cases to be described. It is not clear why one should expect a complete heat balance with the inert-gas-melted or the vacuum-melted Zircaloy-2 since losses by radiation and helium gas heat absorption at least are obvious, however, small. Nevertheless, the difference in anode heat output between the Zircaloy-2 materials is evident.

The variation of heat outputs with arc length at constant current (60 amp) is shown in the graph of Fig. 5. The curve and extrapolated values of Q_c/I for a $^1/_{16}$-in. diam pure-tungsten electrode to zero arc length agree favorably with those of Lancaster[7] at the same order of current. As expected, no significant difference is observed in Q_c/I values for each Zircaloy-2 material. A significant difference is found, however, in the Q_a/I values vs. arc length. The inert-gas-melt curve of Q_a/I vs. arc length lies above the curve for the vacuum-melt material and has a steeper slope. Extrapolated values to zero arc length, for the two materials, show a difference of 1.6 watts per ampere with the inert-gas-melt material value being 11.8 w/amp and that of the vacuum-melt material being 10.2 w/amp.

Table 3—Anode and Cathode Voltage Drops for a Pure-Tungsten Electrode, 0.060 Diameter

	Inert-gas volts	*Vacuum-melt volts*
$V_a + V_c$ from plasma gradient data)	14.2	13.2
$V_a + V_c$ (from calorimetric data)	13.2	11.6
V_c (from calorimetric data)	6.9	6.9
V_a (from calorimetric data)	6.3	4.7
V_a (from both data with Eq. 1)	7.3	6.3
Average V_a	6.8	5.5

Plasma gradient curves shown in Fig. 6 indicate a small but significant difference in the total arc potential versus arc length for the two materials. The inert-gas-melt Zircaloy-2 arc operates at a higher total voltage than does the vacuum-melt material. The difference in the extrapolated values to zero arc length (sum of anode and cathode drops) is approximately 1.0 volt. Comparison with the anode heat outputs at zero arc length shows a difference of 1.6 volts, determined by equating watts per ampere to volts. The cathode drop for each Zircaloy-2 material determined calorimetrically was found to be 6.9 volts as determined from Equation (2a).

The values of the cathode and anode voltage drops are compiled and were calculated from plasma gradient data, Fig. 6, and calorimetric data, Fig. 5 and Table 2.

The lower values of the calorimetric data indicate that losses to the environment were experienced as expected, however, small. The higher values of the plasma gradient might be partially caused by a small IR drop included in the plasma gradient measurements. The agreement of data obtained from the two experimental methods is quite good and substantiates the value of calorimetric determinations of the cathode and anode drops. The potential distribution for a typical arc length for each material is shown in Fig. 7, using the average values of the cathode and anode voltage drops.

As previously mentioned, there are some experiments with the inert-gas-melt Zircaloy-2 for which the anode heat outputs fell below the curve of Fig. 5. In these cases, the flow rate of water was increased from approximately 6.5 ml

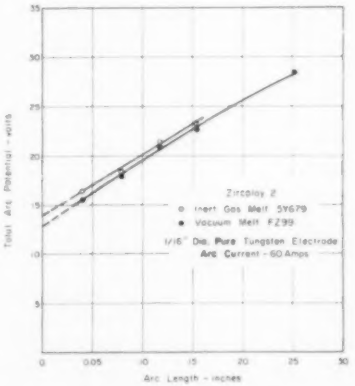

Fig. 6 The variation of total arc voltage with arc length

per sec to approximately 10 ml per sec. This effectively produced a greater degree of quenching on the anode material and therefore would further restrict the amount of energy that would be dissipated to melt the anode. It follows that less anode material would be melted. Data collected at the higher water-flow rate for the vacuum-melt material fell on the curve for the data at the lower flow rate indicating that the anode drop is not being greatly influenced by the amount of energy dissipated in the anode or possibly by the amount of anode material melted. If we assume that the difference in heat output is a function of the diffusion of an impurity out of the anode workpiece, then the depletion of this diffused substance in time as affected by the amount of metal melted could be realized by a limited amount of melting. These results indicate that the anode heat output for the inert-gas-melt material is a function of the volume of Zircaloy-2 melted by the arc which would determine the amount of diffusible impurity. In the calorimetric experiments, the amount of melting was rigorously limited by the transfer of heat by coolant water and could be varied by altering the flow rate of water through the anode portion of the calorimeter. However, keeping the flow rate of the calorimeter at the low value, it was found that the phenomenon of higher anode heat output could be made evident. Since the heat energy was varied by changing the electrical energy input essentially by varying the arc length at constant current, the change in anode and cathode heat output was determined. Both the data on the weld penetration variation with current and the anode heat output variation with arc length show curves that differ in slope and not uniformly displaced, indicating that the difference in amount of weld penetration and anode heat output for the two materials is progressive and depends upon the amount of anode material brought to the energy state of melting.

This brings us to the source of the variance in composition to affect a change in the anode drops which is calculated from the heat balance, Equations 1, 2 and 3.

From a rather complete analysis, both spectrographic and chemical (Table 1), of the two heats of Zircaloy-2, the only apparent differences in composition of any significance are those of the chlorine and hydrogen contents. The greater amounts of these elements are found in the Zircaloy-2 made by the inert-gas-melt method. One would expect, in general, more residual impurities in a melt made at atmospheric pressure than in a melt made by vacuum methods since the diffusion to the surface of the melt and evaporation of impurities with positive vapor pressures would be

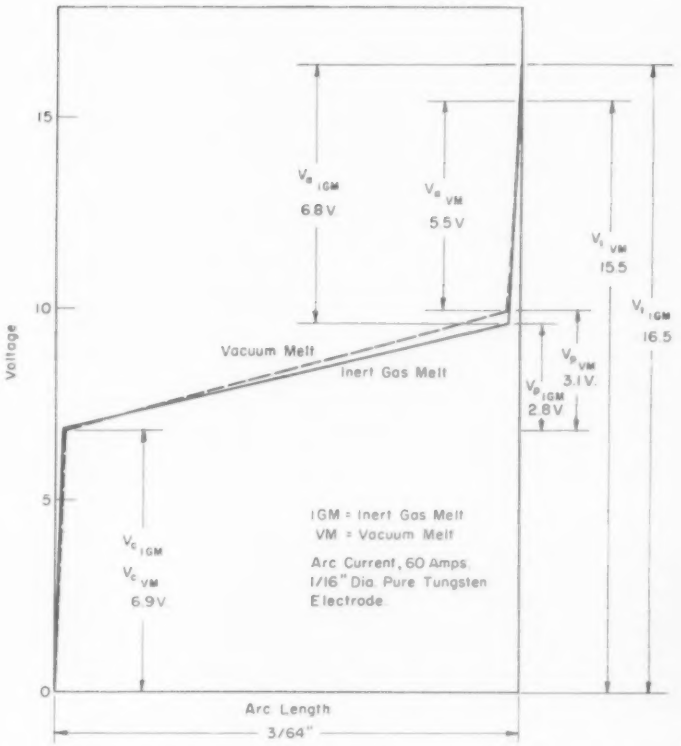

Fig. 7 The potential distribution for a typical arc length with each Zircaloy-2 material

greatly facilitated by the very low gas pressure above the melt.

The influence of electronegative gases (those gases which form negative ions) has been the subject of experiments in glow discharges and on low current intermediate pressure arcs.[9,10,11,12,13] Among these electronegative gases are the halogens: chlorine, bromine, fluorine and iodine. The influence of chlorine and iodine has been described in several works[9] on the influence of negative ions in glow discharges and low-voltage intermediate-pressure arcs. The influence of iodine and chlorine was observed at halogen gas pressures of 0.1 mm Hg by the appearance of a positive column even with the main electrodes only 3 cm apart. It is shown also that negative-ion random current rose to a value equal to that of the positive-ion random current. There are many experiments in the literature that describe the influence of electronegative gases on glow discharges, but few, if any, of their effect on the energy distribution in high-

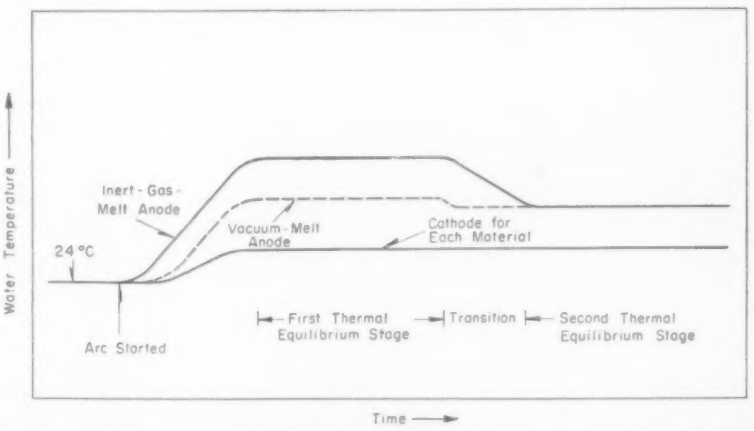

Fig. 8 Comparison of flow calorimetric (time-temperature) curves for inert-gas and vacuum-melt Zircaloy-2 anodes

pressure arcs. More recently, however, the use of sulfur hexafluoride (SF_6) in the extinction of higher pressure arcs has brought to focus the economic importance of the use of halogenated compounds which are effective in attaching electrons to form negative ions. How this activity would cause increases in the anode voltage drop is not clear. The appearance of striations in glow discharges causes the mean energy to increase, possibly due to the occurrence of steeper voltage gradients in the positive column. Also, in the case of the halogens in glow discharges, many more positive ions are needed since the negative component of the current is carried mostly by negative ions instead of electrons.[9] The occurrence of a high negative ion space charge and the need for many positive ions cause an increase in the anode voltage drop.[9] If this latter situation holds for the subject high-pressure arc, the higher chlorine and hydrogen content of the inert-gas melt may explain the reason for the higher anode drop found for the Zircaloy-2 material.

Additional experiments were performed to determine what effect the introduction of a halogen to the arc with a vacuum-melt anode may have on the anode heat output. Tests 3A and 4A were run using a vacuum-melt specimen contaminated with iodine. The iodine was applied as a tincture using absolute ethyl ether as the solvent. The calorimetric data show only a slight increase in anode heat output. However, an almost 100% heat balance was obtained. It was becoming more and more apparent that the cause of the higher anode heat output for the inert-gas-melt material was due to an impurity (chlorine and hydrogen) being evaporated from the melted volume of the weld.

Additional calorimetric experiments were performed with both of the Zircaloy-2 materials to determine if the anode heat output changed after extended times of arcing. Previously, the arc was extinguished after an apparent equilibrium had been reached. This was indicated by no further change in the calorimetric water temperature. As shown by Fig. 8, an extension of arc operating time beyond the first thermal equilibrium revealed that the water temperature for the anode decreased and then attained a second stage of thermal equilibrium. Both anode materials showed the second stage of thermal equilibrium; however, the inert-gas-melt material showed a significantly larger change in thermal-equilibrium temperature, with the second stage fall-

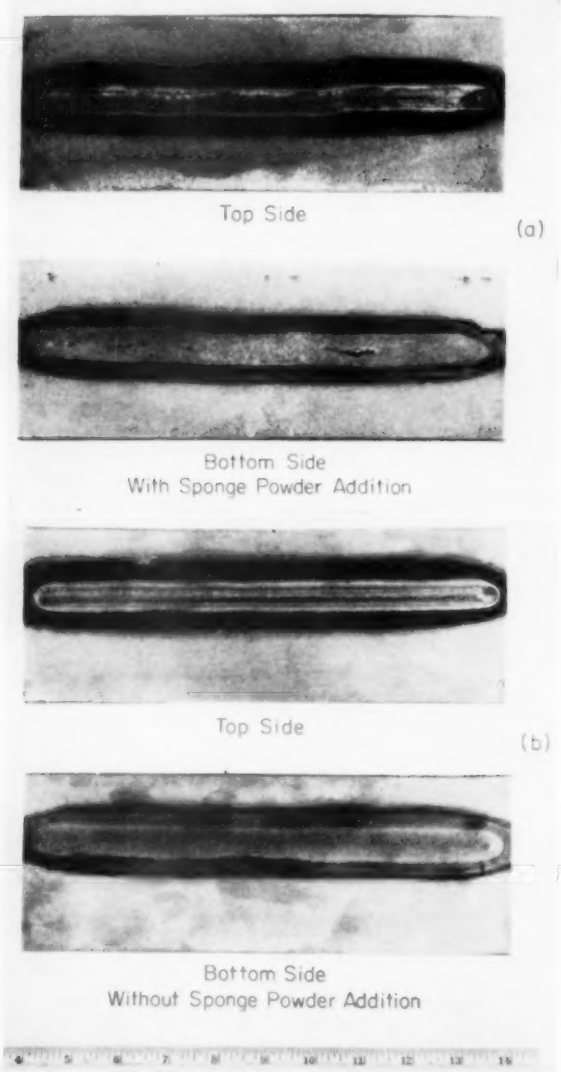

Fig. 9 Impurity (zirconium sponge powder) effect on penetration of vacuum-melted Zircaloy-2

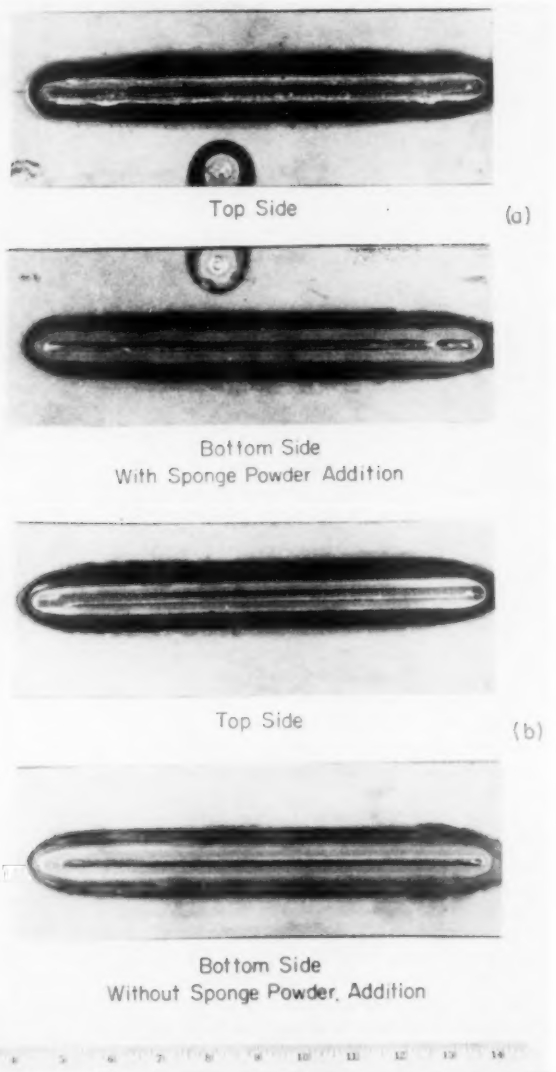

Fig. 10 Impurity (zirconium sponge powder) effect on penetration of atmosphere-melted Zircaloy-2

ing to essentially the same temperature as for the vacuum-melt material. Thermal-equilibrium temperature in the cathodic portion of the calorimeter for each material was the same and showed only one thermal equilibrium stage illustrated in Fig. 8. This evidence indicates that an impurity being evaporated from the anode material is effective in increasing the anode drop and when the impurity had been depleted the anode drop fell. The relative magnitude of the change in temperature from the first stage to the second stage for the anode material is significant.

As a test of the theory and cause of the phenomenon of anode heat output variance in the welding of Zircaloy-2, a proofing test was performed in which impurities were added to the surface of workpiece samples representative of the two arc melting practices. Zirconium sponge, known to contain more impurity than either arc-cast alloy, was prepared in powder form. The zirconium sponge used contained more than 100 ppm chlorine. In preparation for the weld tests, a thin layer of zirconium sponge powder was applied to the line of welding on the workpieces. Each workpiece sample was welded at the same arc current and weld speed. The results of the tests are shown in the photographs of Figs. 9 and 10. The top and bottom sides of each workpiece sample are shown. The photographs show that the penetration was increased in the cases when zirconium sponge powder was added to vacuum and atmosphere-melted Zircaloy-2. Although these tests do not conclusively prove that the chlorine content of the Zircaloy-2 is responsible for the variance in weld penetration and anode heat output, the evidence confirms the influence of impurities and, since chlorine undergoes the greatest variation in content, all evidence points to this impurity as the cause.

Discussion

It has been shown by calorimetric measurements that a significant difference in the anode heat output exists with Zircaloy-2 materials. Also, it appears that the anode heat output is a function of the amount of certain impurities contained in the materials. Furthermore, the diffusion and evaporation of this impurity are manifested by a higher anode heat output. Upon the depletion of this impurity, a lower anode heat output is found, as illustrated by Fig. 8. Of the several residual elements found in the Zircaloy-2 materials, chlorine and hydrogen are outstanding with respect to comparative concentrations in the Zircaloy-2 prepared by the two process techniques. Without exception, in 11 ingots, 3 of inert-gas-melt and 8 vacuum-melt, the chlorine and hydrogen content in the inert-gas-melt material is at least about twice as high as the vacuum-melt material, and in the case of two ingots represented by this experimental work, 5 times in the case of chlorine and 3 times in the case of hydrogen. The analysis of oxygen and nitrogen shows their concentrations in both materials to be nearly the same.

Chlorine is classified as strongly electronegative[10] because its atomic arrangement and chemical behavior are such as to absorb free electrons to form negative ions. The existence of negative ions and their effect in high-pressure arcs is a comparatively new concept. However, the work on glow discharges has conclusively demonstrated the striation effect of the conducting path and the increase in the anode fall. In the electronegativity scale, the order for the halogens varies from iodine, with least electronegativity, to bromine, chlorine and finally fluorine which has the greatest electronegativity. The theory of the effect of negative ions shows merit. It would be expected that the effect would be more pronounced with the use of bromine, chlorine or fluorine. Also, certain halogen compounds such as sulfur hexafluoride are suggested to increase the anode heat output when welding the vacuum-melt material. The concentration of halogen necessary to influence the anode heat output appears to be of extremely low order.

Summary and Conclusions

1. The anode heat output is higher for the inert-gas-melt Zircaloy-2 than the vacuum-melt material.

2. The anode heat output appears to depend on the diffusion and evaporation of an impurity, such as chlorine, from the Zircaloy-2.

3. The higher anode voltage, and higher anode heat output resulting from the impurity, is caused by the formation of negative ions. The source of the electronegative gas would be chlorine, a residual impurity.

4. It is suggested that the control of the chlorine content during the arc melting of the alloy may eliminate the variance introduced in the welding of these materials.

5. As determined calorimetrically, the cathode drop of the helium-gas-shielded $^1/_{16}$-in. diam pure-tungsten arc at 60 amp current is 6.9 volts. The anode drop with Zircaloy-2 anode material was found to vary with the sponge-base-alloy melting practice in the range of 5.5–6.8 volts.

Acknowledgments

The author gratefully acknowledges the assistance of B. Schaaf of the Westinghouse Atomic Power Division in supplying chemical analyses and background information concerning the subject problem. Also, the technical assistance of the Research Laboratory personnel, including Miss Julia Senko and W. Hickam for spectrometric analyses; F. Byrne and W. Slippy for the loan of equipment, and R. J. Wurdack for help in conducting experiments, is appreciated.

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EFFECT OF NEUTRON IRRADIATION ON THE MECHANICAL PROPERTIES OF SOME STRUCTURAL STEELS

A302 steel found to undergo little or no change in room-temperature tensile and impact properties upon irradiation; A201 steel increases in strength, and decreases in ductility and energy-absorption ability with increasing irradiation

BY E. E. BALDWIN

ABSTRACT. Tensile and impact specimens of ASTM A302B steel were irradiated at 500 and 700° F to integrated fast fluxes of 3.8×10^{18} nvt. Notched-bend specimens of ASTM A201 steel were irradiated at 300–400° F to integrated fast fluxes of 4.3×10^{20}. Results indicated little or no change in properties of the A302, but substantial increases in strength and loss of ductility and energy absorption ability of the A201. Substantial recovery of the A201 damage could be accomplished by annealing at 600° F.

Introduction

Within the past several years there has been expended an increasing effort upon the design, development and construction of plants to convert the nuclear energy of the atom into usable power. The feasibility of such efforts has been demonstrated by the successful operation of the submarine "Nautilus" and more recently by the "Sea Wolf." Subsequent to the development of these two power plants, there has been an increasing amount of design and development effort directed toward using the same source of energy for the production of commercial power in stationary power plants. With the increasing cost and threatening depletion or exclusion from world sources of fossil fuel, there will be an ever increasing demand for greater utilization of atomic power, and consequently more and more time, money, and manpower devoted to the design and development of nuclear power plants.

Any nuclear power plant, stationary or mobile, has three major parts: (1) a reactor in which fission of atoms of nuclear fuel such as uranium takes place at a controlled rate, releasing energy in the form of heat and various types of radiation; (2) a heat exchanger where the heat produced by the fission of the nuclear fuel is transferred to a working fluid; and (3) a power conversion unit which transforms the heat to usable energy. In the reactor, radiation produced during the fission of the fuel atoms includes gamma rays, neutrons of varying energies and fission fragments or foreign atoms produced by the fission process and imparted with a high energy by the fission reaction. Investigators have found that these fission radiations and particles may cause changes in the properties of structural materials in the near vicinity of the reactor, the type and magnitude of the change being dependent upon the type of radiation and amount of exposure.

As reviewed by Glen[1], a particle produced by fission may do one of several things when it comes in contact with an atom: (a) collide with one or more orbital electrons; (b) collide elastically with the nucleus; or (c) produce some damage to the nucleus. Models have been proposed and calculations have been made of the probability of each of the above reactions by Holden and Kunz,[2] Bruch, McHugh, and Hockenbury,[3] and others. Sutton and Leeser[4] summarize in tabular form the relative effects of the general types of fission radiation, and along with Kunz and Holden,[5] Wilson and Billington,[6] and Berggren and Wilson[7] tabulate typical examples of the effects of these nuclear particles upon structural materials. In general, these investigators show that the changes listed in Table 1 take place in structural metals and alloys in single crystal and polycrystalline form. The magnitude of the changes listed in Table 1 are dependent upon the condition of the material prior to irradiation (annealed materials show a greater increase in properties than cold-worked material) and amount of exposure. (Changes increase with increased exposure).

The transfer of the heat from the reactor to the heat exchangers of a nuclear power plant, as noted in the introduction, is accomplished by a primary liquid coolant. Water has been used successfully for this purpose and since the temperatures involved are well above its atmospheric boiling point, it must be pressurized to maintain it as a liquid. In certain nuclear vessels containing water as primary coolant, carbon or low-alloy boiler steels such as ASTM A201 and A302, have been used as construction materials. As noted previously, changes in properties of structural materials resulting from neutron irradiation are dependent upon the magnitude of the radiation received. Thus, if a certain carbon steel were subjected to neutron bombardment of 2 different intensities or fluxes for the same length of time, the sample subjected to the highest flux would undergo

Table 1—Changes in Properties of Structural Materials Resulting from Nuclear Fission Radiation

Property	*Change*
Tensile strength	Increase
Yield strength	Increase
Ductility	Decrease
Hardness	Increase
Impact transition temperature	Increase
Electrical resistivity	Increase

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Presented at 1957 AWS National Spring Meeting in Philadelphia, Pennsylvania, April 8–12.

Table 2[8]—Tensile Properties of ASTM A302B Steel in Irradiated and Unirradiated Condition

Ultimate tensile strength, psi	*0.2% offset yield strength, psi*	*Elongation, %*	*Reduction of area, %*	*Change in hardness, R_c*
Unirradiated Control Specimens				
91,200	66,400	25.7	62.5	...
Held at 500° F for 20 Days				
91,500	65,000	26.1	60.7	Not measured
Held at 700° F for 20 Days				
89,800	64,200	26.8	61.1	Not measured
Irradiated at 500° F to 3.7×10^{18} nvt				
95,300	72,100	24.3	59.6	+0.3
Irradiated at 700° F to 3.1×10^{18} nvt				
92,600	67,500	25.5	60.6	+0.5

Table 3[8]—Charpy V-Notch Impact Transition Temperature of Irradiated and Unirradiated ASTM A302B Steel

Specimen treatment	*20 ft-lb transition temperature, °F*
As machined, normalized and tempered	+22
20 days at 500° F	+46
Irradiated at 500° F	+32
20 days at 700° F	+22
Irradiated at 700° F	+32

the greatest change in properties.

There has been occasion at the Knolls Atomic Power Laboratory to investigate the effect of neutron irradiation on the mechanical properties of carbon or alloy steels subjected to two flux conditions. ASTM A302 manganese-molybdenum steel is being used as a pressure vessel to contain a reactor, and in service will be subjected to a relatively low neutron flux that will result in it receiving a total fast* neutron dosage of approximately 5 to 10×10^{18} neutrons per square centimeter during its design life. In addition, ASTM A201 carbon-silicon steel is being used as the construction material for a high pressure-high temperature water irradiation test facility. This material is subjected to a relatively high neutron flux, and because of difficult handling, it is desirable to expose this material to as great a neutron dosage as possible before the properties of the steel change enough to make operation of the facility unsafe.

As a result of these two applications, two experimental programs have been in progress to determine the effect of neutron irradiation on both A302 and A201 steels. The A302 was irradiated to an integrated flux approaching that which the steel would see in service as a reactor pressure vessel (5 to 10×10^{18} nvt—fast). The A201 steel was exposed to increasing amounts of irradiation [1 to 4×10^{20} nvt], in order to get an indication of the safe operating life of the experimental facility.

* "Fast" neutron—referred to in this paper as one having an energy in excess of 1 mev.

ASTM A302B Steel

To determine the effect of neutron irradiation in the order of 10^{19} nvt upon the mechanical properties of ASTM A302 manganese—molybdenum steel, tensile and impact specimens were irradiated in an experimental hole of the Brookhaven National Laboratory reactor. The experimental irradiation facilities of the Brookhaven reactor were used because the neutron flux received by the specimens was similar to that expected in the service

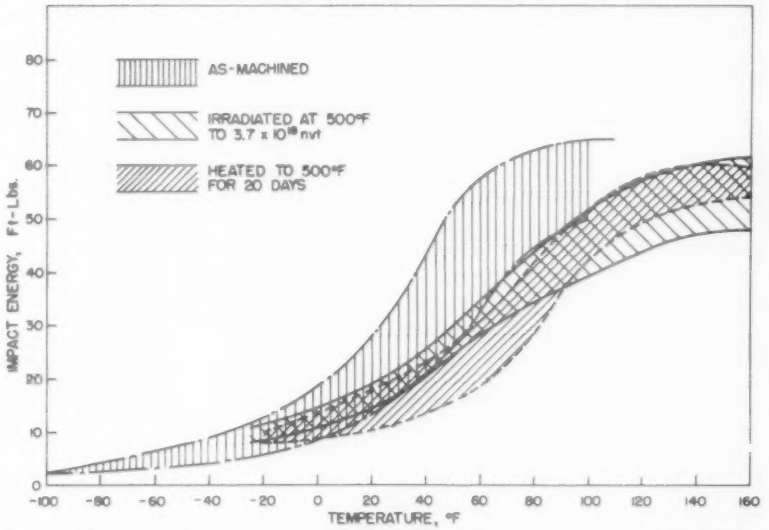

Fig. 1 Normalized and tempered ASTM A302B Charpy V-notch impact—500° F treatment

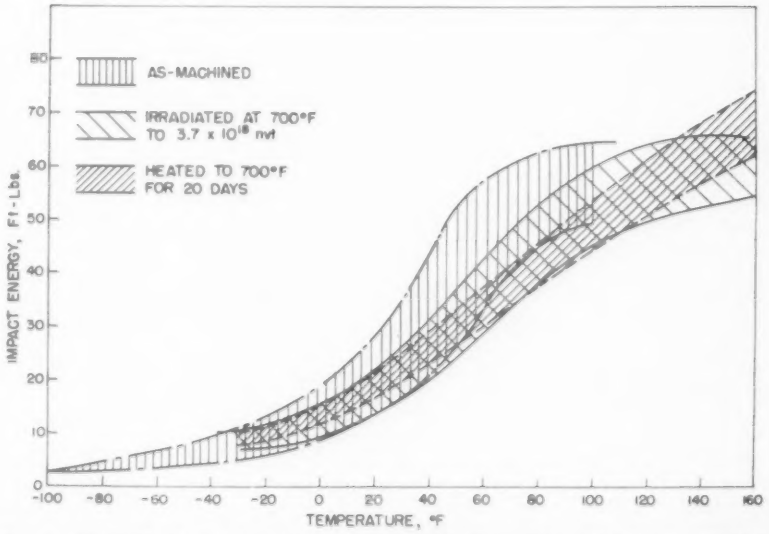

Fig. 2 Normalized and tempered ASTM A302B Charpy V-notch impact—700° F treatment

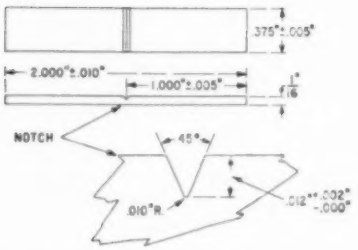

Fig. 3 Notched-bend specimen

of the reactor pressure vessel.

Details of the specimens used, irradiation conditions, and test procedure followed have previously been reported.[8] Summaries of the tensile and impact data obtained in this investigation are listed in Tables 2 and 3. A graphical representation of the impact energy versus temperature curves is shown in Figs. 1 and 2.

Results

Surveying the results of the A302 investigation listed above, it can be seen that there was little or no effect of the irradiation on the tensile or impact properties of the steel investigated. There was some slight variation in the properties but these can be accounted for by normal testing variation.

ASTM A201 Steel

To determine the effect of neutron radiation on the properties of ASTM A201 carbon-silicon steel used in the construction of a high-temperature, high-pressure irradiation facility, specimens of this material were irradiated to increasing amounts of integrated fast neutron flux, and tests made of these specimens to determine the effect of this radiation on the mechanical properties of this material.

Experimental Restrictions and Specimen Selection

In order to obtain a fast neutron flux which was equal to or greater than that received by the experimental facility, irradiation facilities had to be used which necessitated the sealing of test specimens in capsules approximately $1^1/_2$ in. in diam, and lengths ranging from 4 to 8 in. In addition, because of the demand on this particular facility, only a limited number of capsules could be irradiated. A third limitation was imposed by the facts that (1) it was necessary to start the investigation at the earliest possible date and (2) only a limited supply of A201 steel in the form of $^1/_4$-in. thick plate was available for test specimens.

With these limitations, it was obvious that standard-size tensile and impact specimens could not be used, and since it was desirous to irradiate a number of specimens under the same conditions, even sub-size tensile and impact specimens would not be suitable. Since previous work had shown that one of the major effects of neutron radiation damage of carbon steels is the embrittling or loss of ductility, and since one of the major worries of the effect of neutron radiation on the experimental facility was failure due to the combination of the presence of a notch and embrittlement, it was decided to irradiate notched bend specimens shown in Fig. 3 for the initial part of the investigation, followed by irradiation of sheet-type tensile specimens under conditions equivalent to the bend specimens. By this procedure, it was felt that a comparison of the test results on the bend specimens could give a more or less qualitative indication of the effect of irradiation, and tests of the tensile specimens would give a quantitative explanation of the bend test results. The bend test portion of this investigation has been completed and is described herein. The tensile tests have yet to be completed, and will be reported at a later date.

Irradiation Conditions

Three capsules, each containing 20 bend specimens, were irradiated to integrated fast neutron fluxes of 9.9×10^{19}, 2.5×10^{20} and 4.3×10^{20} nvt respectively. When the specimens were encapsulated, they were prevented from coming into contact and causing local hot spots during irradiation, and the capsule was evacuated and filled with a protective atmosphere prior to closure. It was calculated from the design of the capsule that the specimens were at a temperature of approximately 300 to 400° F during irradiation.

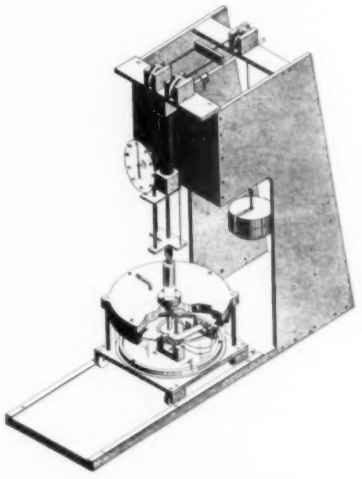

Fig. 4 Bend tester for radioactive materials

Table 4—Bend Test Results of Irradiated ASTM A201 Steel

Calculated integrated fast neutron flux, nvt	*Test temperature, ° F*	*No. of tests*	*Average energy absorbed, in.lb*
9.9×10^{19}	RT	3	1.9
	200	1	4.5
	300	3	4.3
	400	3	5.6
	500	2	...
	600	1	>11.9
	600/1 hr/RT*	1	15.6
2.5×10^{20}	RT	3	3.2
	200	3	4.3
	400	3	6.8
	600	2	9.4
	600/1 hr/RT*	1	13.4
4.3×10^{20}	RT	3	1.8
	200	3	3.1
	400	3	5.0
	600	3	8.3
	600/1 hr/RT*	3	14.0
	600/1 hr/600†	1	10.3

* Annealed at 600° F for 1 hr—tested at RT.
† Annealed at 600° F for 1 hr—tested at 600° F.

Table 5—Room Temperature Hardness of Irradiated and Annealed ASTM A201 Steel

Integrated fast flux, nvt	*Treatment*	*Hardness, R_A*	*Change in hardness, R_A*
None, as received	...	43.0	0
9.9×10^{19}	As irradiated	61.9	+18.9
9.9×10^{19}	Annealed 1 hr at 600° F	55.1	+12.1
2.5×10^{20}	As irradiated	62.9	+19.9
2.5×10^{20}	Annealed 1 hr at 600° F	57.8	+14.8
4.3×10^{20}	As irradiated	64.5	+21.5
4.3×10^{20}	Annealed 1 hr at 600° F	51.1	+ 8.1

Testing

When returned after irradiation, the capsules were opened and tested in the Radioactive Materials Laboratory at the Knolls Atomic Power Laboratory. Tests conducted included Rockwell A hardness measurements, and bend tests at room and elevated temperature. The bend tests were conducted in the apparatus shown in Fig. 4.[9] For conduct of tests at elevated temperature, the specimens were heated by a nichrome resistance heater.

The bend tests were conducted by supporting the specimen as a simple beam with the notch at the bottom in the center of a 1.5-in. span. The load was applied in the center opposite the notch and a record made of load and deflection to failure. From these data, plots were made of the load-deflection curve for each specimen.

Results

Using the test conditions outlined above, the data obtained from the test specimens are listed in Tables 4 and 5. The energy absorbed was determined by measuring the area under each load-deflection curve to the point of specimen fracture. In addition to the above tables, average load-deflection curves are shown for specimens in each condition in Figs. 5, 6 and 7.

Discussion

The data presented herein gives an indication of the effects of neutron irradiation on the mechanical properties of low-alloy steels under several different conditions. The data determined for the A302 steel showed the effect when such materials are irradiated at elevated temperatures to integrated fluxes of 10^{19} nvt (fast) or less. On the other hand, with the data for the A201, the effect of irradiation to integrated fast neutron fluxes in excess of 10^{20} nvt, and annealing and elevated temperature is determined.

The experimental evidence for the A302 is obtained in the form of standard tensile and impact properties. For the A201, however, the data were obtained in the form of load-deflection curves for notched bend specimens, and not test data from standard tensile specimens. Examination of the curves shown in Figs. 5, 6 and 7 indicates that some insight can be gained on the effect of irradiation on standard mechanical properties. Since the dimensions of the area under the curves are in inch-pounds, this is an energy expression, and can be used as a measure of energy absorption. By comparing the maximum deflection to fracture for each test condition, a comparison of ductility can be obtained. Finally, a qualitative comparison can be made of strength by noting the maximum load and the load at deviation from linearity

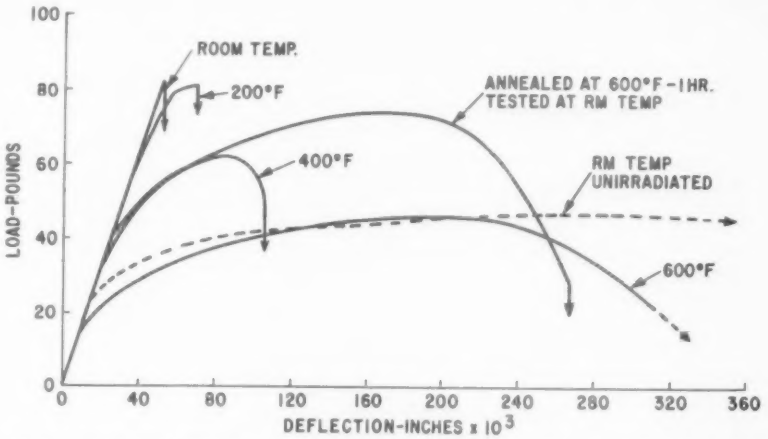

Fig. 5 Load-deflection curves of A201 notched-bend specimens irradiated to a fast flux of 9.9×10^{19} nvt

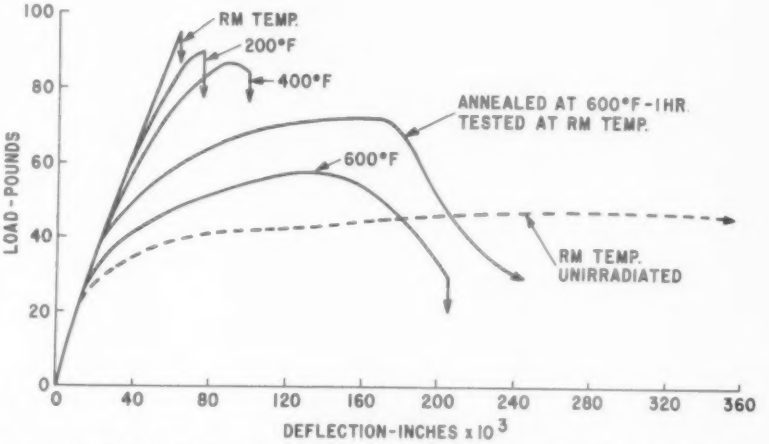

Fig. 6 Load-deflection curves of A201 notched-bend specimens irradiated to a fast flux of 2.5×10^{20} nvt

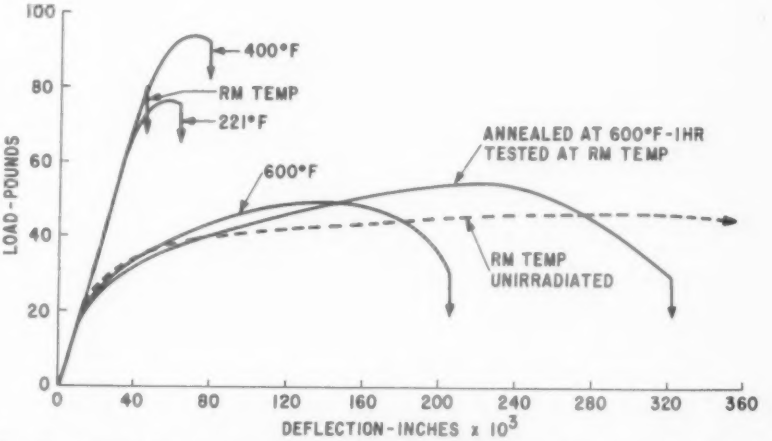

Fig. 7 Load-deflection curves of A201 notched-bend specimens irradiated to a fast flux of 4.3×10^{20} nvt

of the load-deflection curve. This comparison is not felt to be as valid as the other comparisons because of the stress and strain concentration properties of the notch.

In reviewing the data reported herein on the tensile and impact properties of A302 manganese-molybdenum steel, it can be seen that under the experimental conditions reported, there was no detectable change in the tensile or impact properties. Comparison of these data with that on similar materials published by Berggren and Wilson[7] indicates that for integrated fast neutron fluxes less than 10^{19} nvt, little or no property changes can be expected. In addition, the tensile and impact properties showed no change when specimens were heated to the same temperatures and for the same lengths of time as the irradiated specimens. The irradiation temperature, therefore, evidently did not produce any annealing effects. In addition, microstructural studies indicated no difference in the microstructure between the as-received and heated specimens.

On the basis of the evidence obtained, therefore, it seems logical to conclude that ASTM A302 manganese-molybdenum steel when irradiated to integrated fast neutron fluxes of approximately 4×10^{18} nvt at 500 and 700° F undergoes no measurable change in tensile and impact properties.

The data reported herein on the A201 steel present quite a different picture. For this steel, each specimen was irradiated to an integrated fast neutron flux of 10^{20} nvt or greater, and the data reported by Berggren and Wilson[7] and Bleiberg[10] on similar steels (ASTM A106 and ASTM A212) show marked increases in hardness, yield strength, and impact transition temperature and decrease in ductility. From a study of these data one can obtain an insight into the effects of neutron irradiation, elevated temperature testing and annealing on the mechanical properties of A201 carbon-silicon steel.

If one establishes as a criteria for ductility the deflection to fracture of the bend specimens tested, examination of Figs. 5, 6 and 7 indicates (1) in general, for any particular temperature, the ductility decreases with increasing amounts of irradiation and (2) for any given amount of irradiation, the ductility increases with temperature. Minor variations in these general trends occur, but it is felt that these variations are due to the stress and strain concentration introduced by the notch.

The effect of radiation, temperature and annealing upon yield strength can be evaluated if one selects as a criteria for this evaluation the departure of linearity of the load-deflection curve. Again comparing the load-deflection curves for each of the three irradiation conditions, one can see that, with increasing amounts of radiation, the yield strength at any temperature increases, and that the yield strength decreases with increasing temperature for any given amount of irradiation.

The energy absorption ability of the material and the effects of irradiation on this property are determined by comparing the areas under the curve. In Fig. 8 the energy absorbed has been calculated and plotted versus test temperature. These data indicate that, the energy absorption increasing with increasing temperature, with the exception of 600° F, irradiation within the limits studied has little effect on this property. At 600° F, however, there is a definite decrease in the energy absorption with increasing irradiation.

Since irradiation damage is thought to be primarily caused by lattice defects, annealing after irradiation should repair these defects. The effect of annealing at 600° F is dramatically illustrated by comparing the curves for the unirradiated room temperature specimen, the irradiated room temperature specimen and the specimen tested at room temperature after annealing at 600° F for 1 hr. At each irradiation level, there is recovery of an appreciable amount of the pre-irradiation properties by the annealing treatment.

Examination of the load-deflection curves indicates that there is a rather wide difference between the properties at 400° F and those at 600° F. To determine the effect of various annealing times at 500° F, specimens which were irradiated to 4.3 x 10^{20} nvt were annealed at 500° F for 1, 10 and 100 hours and tested at room temperature. The resultant load-deflection curves are shown in Fig 9, together with the curve for the specimen annealed at 600° F for 1 hr.

Examination of Fig. 9 indicates that, for A201 steel, an anneal at 500° F for up to 100 hr has only a fraction of the effect produced by annealing 1 hr at 600° F.

Although these annealing data show that a major portion of the damage caused by radiation in A201 steel can be recovered by annealing at elevated temperatures after irradiation, it does not indicate that radiation damage occurring in A201 steel specimens will be concurrently healed by irradiating them at the elevated annealing temperature. Recent data have indicated[11] that for materials in which the radiation damage can be removed by high-temperature annealing after irradiation, the damage is not completely removed when the annealing and radiation take place simultaneously.

Work to Be Done

As pointed out, the notched-bend tests of A201 gave only qualitative data, and that sheet tensile specimens will be tested to explain and amplify the results of the bend tests. In addition, it is planned to irradiate smooth and notched-bar round tensile specimens to greater integrated fluxes than

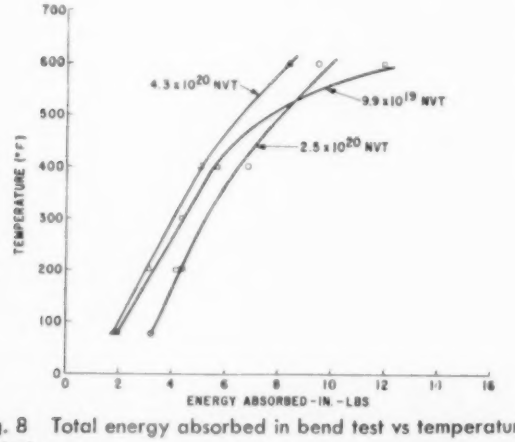

Fig. 8 Total energy absorbed in bend test vs temperature of test

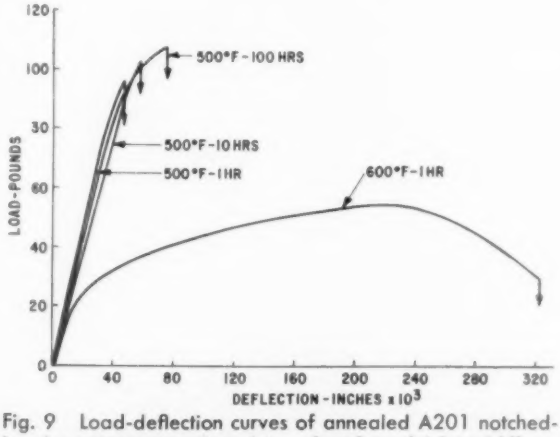

Fig. 9 Load-deflection curves of annealed A201 notched-bend specimens, irradiated to a fast flux of 4.3×10^{20} nvt, tested at room temperature

the bend specimens, and full-size Charpy V-Notch impact specimens to equivalent integrated fluxes. The tensile specimens will be used to study the effect of increased irradiation and annealing behavior, and the impact specimen will be used to correlate energy absorbed by the bend specimens with impact energy.

Conclusions

From the results obtained in this investigation, the following conclusions can be drawn:

1. ASTM A302 manganese-molybdenum steel undergoes little or no change in its room temperature tensile and impact properties when irradiated to integrated fast fluxes less than 10^{19} nvt.

2. ASTM A201 carbon-silicon steel when irradiated to integrated fast neutron fluxes in excess of 10^{20} nvt increases in strength, and decreases in ductility and energy absorption ability with increasing irradiation as determined by notched-bend tests. The properties of this material approach those of the unirradiated material with increasing temperature and a major portion of the radiation damage can be recovered by annealing for 1 hr at 600° F.

The investigation of A201 steel indicates a general philosophy which is recommended for any radiation damage program which is to be conducted on a material proposed for a specific use. The conditions under which the material is irradiated should simulate as closely as possible the design operating conditions of the equipment for which material is to be or is proposed for use. These conditions include temperature, environment and neutron flux.

Acknowledgment

The author wishes to express his appreciation for the cooperation and efforts of M. Fox, R. W. Powell, and J. J. Floyd of the Brookhaven National Laboratory and R. L. Mehan, F. W. Wiesinger, and D. J. Ruggiero of the Knolls Atomic Power Laboratory, who made this publication possible.

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FLASH WELDING ALUMINUM TO COPPER TUBING

BY E. SCHNEIDMADL

The refrigeration industry's requirements for butt welds joining copper to aluminum tubing are best met by flash welding. A new type of pneumatic flash welder now is available having the required characteristics for this exacting type of welding. The new welder is well adapted to provide the required inverse logarithmic form of flashing speed. If L is the length flashed and t is the time of flashing, the flashing speed

$$V = (L/t) = \{(P - C_1)/[C_2(T_w - T_i)A]\}$$

where P is power, T_w is welding temperature, T_i is initial temperature, A is cross-sectional area to be welded and C_1, C_2 are constants.

The new welder has no cam. The movable platen is connected to the piston of an air cylinder. Oil on the opposite side of the piston controls the motion of the platen. A control valve is arranged so that the platen travels back and forth as desired. The clamps also are pneumatic.

The copper tubing was soft, 99.9% purity, and between 3.150-in. OD, 0.630-in. wall and 3.158-in. OD, 0.689-in. wall. The aluminum tubing was soft, 99.7% purity, and between 3.142-in. OD, 0.535-in. wall and 3.158-in. OD, 0.512-in. wall.

The welding conditions were:

Initial extension, copper	0.217 in.
Initial extension, aluminum	01532 in. (2-deg bevel)
Total flash-off	0.24 in.
Flashing time	30 cycles
Total upset	0.32 in.
Upset time	3 cycles
Upset velocity	31 fps
Upset current	18,000 amp
Upset current time	$1^1/_2$ cycles

Immediately after upset, the joint is drawn back into a recess in the clamps and is struck a forging blow by the pneumatic clamp. This is similar in principle to the double upset used in America. The high upset pressure is designed to force $CuAl_2$ compound from the joint.

Nitrogen or carbon dioxide under 5 lb pressure is supplied to the interior of the tubing during welding. The gas tends to make results more uniform and blows out flash from the inside of the tubing.

Abstract by **Gerard E. Claussen** of "Die Herstellung Hochwertiger Verbindungen Zwischen Kupfer und Aluminum Durch Abbrenn-Stumpfschweissung," published in *Schweissen und Schneiden*, **9**, 59–64 (1957). Reprinted from the *Vereinigte Deutsche Metallwerke AG*, Werdohl, Germany.

Dr. Claussen is associated with the Development Laboratories, Linde Company, Newark, N. J.

SELF-FLUXING AIRPROOF BRAZING ALLOYS

Paper presents recent experimental results and brings up to date the theory involved in the formulation of self-fluxing, airproof brazing alloys

BY NIKOLAJS BREDZS AND HARRY SCHWARTZBART

ABSTRACT. This paper presents a progress report on a program to develop self-fluxing, airproof brazing alloys. Although some experimental data are presented, the emphasis is on the theoretical considerations which govern the formulation of such alloys.

The paper may be summarized as follows:

1. A self-fluxing, airproof brazing alloy can be made by adding another highly reducing element to a lithium-bearing brazing alloy. This element must have the same high affinity for oxygen at brazing temperatures as has lithium. The most important prerequisite for obtaining airproof brazing properties is that the binary phase diagram of the two oxides, the lithium oxide and the oxide of the other highly reducing element, must have at least one eutectic point with a melting point considerably below the solidus temperature of the given brazing alloy.

2. It appears that the combination lithium-boron is almost ideal because: (*a*) both lithium and boron have high affinity for oxygen at brazing temperatures; (*b*) according to the binary phase diagram Li_2O-B_2O_3, the two oxides form a series of low-melting compounds and mixtures of compounds; and (*c*) lithium borates have excellent fluxing properties.

3. Brazing experiments have shown the correctness of the foregoing approach. A Cu-Ni-Li-B alloy has been used to braze steels in air, without fluxes or protective atmospheres. Although this particular alloy is not commercially feasible because of poor corrosion resistance and a tendency for segregation in its preparation, it demonstrates the principles outlined. Both difficulties are due to the complete insolubility of lithium in solid nickel or copper, and due effort is being and will be devoted to a search for suitable and practical alloys capable of dissolving both lithium and boron.

Introduction

The Armour Research Foundation has been working for some time on a program to develop self-fluxing, airproof brazing alloys. Favorable results have been obtained and patents applied for and issued. Papers have been published[1,2] describing the results up to date of their publication. The purpose of this publication is to present a further progress report on this general development, and, more specifically, to bring up to date the theory involved in the formulation of self-fluxing airproof brazing alloys. Some of the recent experimental results are presented, some are still withheld because of patent considerations; but, above all, the guiding principles are discussed as they are currently understood, so as to stimulate further activity among research workers in the long-neglected field of brazing.

It is necessary at the outset to define the term "self-fluxing, airproof" as used in this presentation. By self-fluxing, airproof brazing alloys are meant alloys which can be used for brazing in air without any additional fluxes or protective atmospheres. The word "additional" is added to the definition to differentiate external fluxes from fluxes which are formed *in situ* as a result of the reduction reactions occurring between components of the filler metal and the oxides on the surface of the base metal. It is possible to establish a definition of self-fluxing alloys, as differentiated from self-fluxing, airproof alloys, as those with which one can braze without additional fluxes but in some kind of protective atmosphere (neutral, slightly reducing or slightly oxidizing). Absolute differentiation between these atmospheres is difficult because of the effect of the dew point among other things, on brazing. Thus, argon is not inert if the dew point is so high that the base metal will oxidize at the temperatures involved. However, according to the arbitrary definitions used in this paper, all of these atmospheres require only a self-fluxing alloy, whereas air requires a self-fluxing, airproof alloy, if brazing is to be done without an additional flux.

One might ask "What is the advantage of using a self-fluxing, airproof alloy over using an external flux, if a flux is present during brazing in both cases?" The primary disadvantage involved with a flux is the possibility of flux entrapments which weaken the joint. The chief advantage of a self-fluxing airproof alloy is presented in that (aside from production significance of omitting fluxing operation) no excess flux is formed; only that amount which is actually needed is formed *in situ*. It is believed, therefore, that the possibility of flux entrapments is greatly lessened. In any case, the amount of flux involved is certainly much less than if an external flux is used. By the same token, this can be a disadvantage in some production operations. Sometimes excess flux is used to protect parts of the base metal away from the actual joint which will be heated during brazing. Such protection will not be afforded if a self-fluxing, airproof alloy is used alone.

The first self-fluxing brazing alloys were developed a long time ago. For instance, the well-known copper-phosphorus and copper-silver-phosphorus brazing alloys have been used for commercial brazing purposes for many years. However, the self-fluxing properties of these alloys were not recognized in the earliest years of their use. Only in later years was it observed that in brazing copper and copper alloys with the phosphorus-bearing alloys no fluxes or reducing atmospheres were necessary. It was found that at brazing temperatures phosphorus reduces the oxides on the surfaces of copper base alloys, making the phosphorus-bearing brazing alloys self-fluxing and airproof.

Requirements of a Self-Fluxing, Airproof Brazing Alloy and Possibilities of Meeting These Requirements

The principal requirements of a self-fluxing, airproof brazing alloy are as follows:

1. The brazing alloy must contain a deoxidizing element or elements which reduce the oxides on the surface of the base metal.

2. The melting point of the products of the reduction reaction with the base metal oxides must be below the brazing temperature. A related requirement is that the melting point of the products

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of the oxidation reaction between the filler metal and the air be below the brazing temperature.

3. The viscosity of the products of the reduction and oxidation reactions must be low enough so that they can be displaced by the filler metal in the capillary gap.

These three principal requirements will be discussed in detail.

Affinity for Oxygen

In Table 1 the oxygen affinity is expressed by the free energy of the oxidation reaction for a series of reducing elements at 227, 727, 1227 and 1727° C. These data were presented by L. M. Pidgeon[3] and are the most recent determinations of the free energies.

Consideration of free energies of oxidation reactions is a possible starting point for the development of self-fluxing brazing alloys. It should be borne in mind, however, that use of thermodynamics alone is very much an oversimplification of what occurs during brazing. In short, thermodynamics is a science of equilibrium conditions and brazing is probably as far from an equilibrium process as any to be found in metallurgy. In order to understand completely the formulation of self-fluxing alloys one would have to know the kinetics of the process; one would have to know, among other things, (1) the rates of the oxidation reactions, the free energies of which are listed in Table 1; (2) the solubilities of the oxides in the base and filler metals; and (3) the phase diagrams among the various compounds present.

The second column in Table 1 shows the free energies of the oxidation reactions at 727° C. This temperature is close to the average practical brazing temperature of most of the silver-base and copper-base brazing alloys. The seven most effective deoxidizing elements are Al, U, Li, Ba, Mg, Be and Ca. In the course of this program it has been shown [1,2] that of all these deoxidizers (U was not investigated) only lithium can be used alone in a brazing alloy to impart self-fluxing properties. The consideration which excludes the use of the other deoxidizers alone is the melting point of the oxide formed.

Melting Point of the Products of Reduction and Oxidation

In Table 2 are listed the melting points of the oxides of a series of elements which have the highest affinity for oxygen at brazing temperatures. It can be seen that the melting points of these oxides are considerably higher than the liquidus temperatures of the highest-melting brazing alloys, and even higher than the melting temperatures of the common base metals, copper and steel. From the data presented in Table 1 it is evident that by brazing a base metal with a self-fluxing brazing alloy containing Ti, Al, Ba, Li, Mg, Be or Ca, the base metal oxides on the base metal-filler metal interface will be reduced. However, as a result of this reaction, the base metal oxides on the base metal-filler metal interface will be replaced by a highly refractory oxide of the reducing element. For instance, by using a self-fluxing brazing alloy containing magnesium for brazing of steel, which in a neutral or slightly oxidizing atmosphere is covered by a thin film of iron oxides, the iron oxides will be reduced and replaced by a layer of MgO which is just as detrimental for obtaining sound brazed joints as are the iron oxides. Hence, the first part of the second requirement of a self-fluxing brazing alloy, namely, that the products of the reduction reaction be molten at the brazing temperature.

The second part of the second requirement, namely, that the product of the oxidation of the filler metal in air be molten at brazing temperature, is not, as it might at first glance appear to be, identical to the first part. The composition of the film formed at the air-filler metal interface is different from the composition of the film at the base metal-filler metal interface. If the melting point of the film at the air-filler metal interface is above the brazing temperature, this film will encapsulate the molten filler metal, preventing it from flowing.

Of all the oxides listed in Table 2, lithium oxide has the lowest melting point, 1430° C. However, even this melting point is about 500° C higher than the average brazing temperature of most of the commercial brazing alloys. Moreover, the melting point of Li_2O is almost as high as the melting point of the most common base metal, low-carbon steel. Consequently, it might be imagined that the comparatively high melting point of Li_2O should be detrimental for the self-fluxing properties of lithium-bearing brazing alloys even for brazing of such high-melting base metals as are the commercial carbon and alloy steels. However, most surprisingly, experimental investigation of the wettability of low-carbon steel, drill rod and 303 stainless steel with molten 1% Li – 99% Ag, and 1% Li – 99% Cu alloys have shown that these alloys have excellent self-fluxing properties. Small additions of lithium to silver results in self-fluxing brazing alloys

Table 2—Melting Points of the Oxides of Metals Which Have the Highest Affinity for Oxygen at Brazing Temperatures

Metal	*Oxide*	*Melting point of the oxide, ° C*
Ti	TiO	1760
Al	Al_2O_3	2030
Ba	BaO	1925
Li	Li_2O	1430
Mg	MgO	2770
Be	BeO	2530
Ca	CaO	2580

Table 1—Free Energy of Formation of Oxides in K-Cal per Oxygen Gram-Atom[3]

At 227° C		*At 727° C*		*At 1227° C*		*At 1727° C*	
Ag	+0.06	Cu	−23.3	Cd	−14.4	Na	−7.9
Hg	−8.8	Pb	−28.7	Cu	−15.2	Cu	−10.7
Cu	−31.5	Ni	−35.0	Pb	−18.7	Ni	−13.0
C (O)	−37.1	Co	−38.8	Ni	−24.2	Zn	−15.0
Pb	−40.4	Cd	−37.7	Co	−29.5	Co	−19.9
Ni	−46.1	Fe	−47.8	Na	−38.6	Fe	−33.8
Co	−47.9	C	−47.9	Zn	−38.9	Cr	−49.1
Cd	−50.4	Zn	−61.4	Fe	−40.0	Mn	−55.1
Fe	−55.5	Na	−65.5	C	−58.3	U	−59.6
Zn	−71.3	Cr	−69.7	Cr	−59.5	V	−60.5
Cr	−81.6	Mn	−74.5	Mn	−65.6	Si	−61.9
Na	−83.0	V	−79.0	V	−69.5	B	−65.0
Mn	−83.1	B	−81.7	B	−73.1	C	−68.5
V	−89.0	Si	−83.4	Si	−73.1	Ti	−70.1
B	−91.2	Ti	−91.1	Ti	−80.5	Mg	−76.1
Si*	−94.0	Al	−108.2	Li	−92.0	Al	−82.0
Ti†	−101.2	U	−109.0	Al	−95.1	Ba	−86.0
U	−119.1	Li	−110.2	U	−98.8	Ca	−95.5
Al	−120.7	Ba	−110.5	Ba	−99.0	Be	−96.6
Ba	−121.5	Mg	−117.7	Mg	−101.3		
Li	−127.7	Be	−119.6	Be	−108.3		
Mg	−130.8	Ca	−126.0	Ca	−113.3		
Be	−131.3						
Ca	−138.2						

* Quartz.
† Rutile.

which are capable of brazing carbon and alloy steel without either flux or reducing atmospheres. It has been shown that the tensile strength of steel joints brazed with 1% Li – 99% Ag alloy is almost as high as the tensile strength of the steel joints brazed with pure silver.

One explanation why the comparatively high melting point of Li_2O is not detrimental for obtaining good self-fluxing properties of lithium-bearing brazing alloys is that lithium oxide forms low-melting slags with most of the metallic oxides. For instance, tungsten oxide, WO_3, which has a melting point of 1473° C, forms with lithium oxide a low-melting compound, Li_2WO_4, which has a melting point of only 742° C. To provide more evidence for this hypothesis, in Table 3 are listed the melting points of some of the high-melting oxides, and also the melting points of some of the compounds which these oxides form with Li_2O. These data only confirm the fact, well known from analytical chemistry, that high-melting refractory oxides can be easily dissolved in the so-called "alkali melts."

However, for a complete understanding of the thermochemical mechanism of the self-fluxing process with lithium-bearing alloys, it is necessary to know the phase diagrams of the oxides of metals involved in this process. For instance, in order to explain the self-fluxing process in the brazing of steel with lithium-bearing filler alloys, it is necessary to know the Li_2O-FeO binary phase diagram. Unfortunately, the binary phase diagrams of the systems Li_2O-FeO, Li_2O-Fe_3O_4 and Li_2O-Fe_2O_3 have not been investigated, and no data are available on the melting points of lithium oxide-iron oxide compounds or mixtures of these compounds.

An additional factor, which might also contribute to the lowering of the melting point of Li_2O, is the formation of small amounts of LiOH and Li_2CO_3 during the brazing process. It has been observed that lithium-bearing brazing alloys show better self-fluxing properties in a less dry protective atmosphere than in a very dry one. Considering the extremely high affinity of Li_2O for H_2O and CO_2, it is possible that in heating lithium-bearing brazing alloys in an atmosphere not entirely free of H_2O and CO_2, some small amounts of LiOH and Li_2CO_3 will form simultaneously with Li_2O on the surface of the brazing alloy. These small quantities of LiOH and Li_2CO_3 might considerably lower the melting point of Li_2O.

The melting points of the lithium compounds listed in Table 3 show that some of these compounds have a lower melting point than the solidus temperatures of most of the copper-base and silver-base brazing alloys. Especially low are the melting points of the compounds Li_2CrO_4, Li_2MoO_4 and $LiBO_2$. The low melting points of these compounds can perhaps be taken advantage of for developing self-fluxing, airproof brazing alloys. Namely, an airproof brazing alloy can be composed by adding another highly reducing element to a lithium-bearing brazing alloy. This element should have about the same high affinity for oxygen at brazing temperatures as has lithium. In heating such an alloy in air, two oxides will form simultaneously on the surface: lithium oxide and the oxide of the second highly reducing element. The most important requirement for obtaining airproof brazing properties is that the binary phase diagram of these two oxides have at least one eutectic point with a melting temperature considerably below the solidus temperature of the given filler metal. If this requirement is fulfilled, then, by heating such an alloy in air, the low-melting, liquid mixture of the oxides of the highly reducing elements will form on the surface of the filler metal a long time before the filler metal melts. This low-melting, liquid mixture of the oxides will constitute a flux which will protect the brazing alloy from any further oxidation during the melting process and the subsequent brazing process. Furthermore, this low-melting, liquid mixture of the oxides might even dissolve the oxides on the surface of the base metal, provided that the quantities of lithium and of the other highly reducing element are sufficiently high to form enough of the low-melting, liquid flux.

Table 3—Melting Points of Some Metal Oxides and of Some Compounds Which These Oxides Form with Lithium Oxide

	Oxide		Compound with Li_2O	
Element	*Formula*	*Melting point, ° C*	*Formula*	*Melting point, ° C*
Al	Al_2O_3	2030	$LiAlO_2$	Over 1625
Cr	Cr_2O_3	1990	Li_2CrO_4	517
Mo	MoO_3	795	Li_2MoO_4	705
Si	SiO_2	1713	Li_2SiO_3	1201
			Li_4SiO_4	1256
Ti	TiO	1760	$Li_2O \cdot 3TiO_2$	1333
W	WO_3	1473	$LiWO_4$	742
B	B_2O_3	450	$LiBO_2$	861

According to these requirements, it has been found that the combination of lithium and boron, for the following reasons, is almost ideal for composing airproof brazing alloys.

1. Both lithium and boron have high affinity for oxygen at brazing temperatures (see Table 1). Accordingly, during the heating and the subsequent melting process Li_2O and B_2O_3 should both form on the surface of the brazing alloy.

2. According to the binary phase diagram Li_2O-B_2O_3 (see Fig. 1), Li_2O and B_2O_3 form a series of low-melting

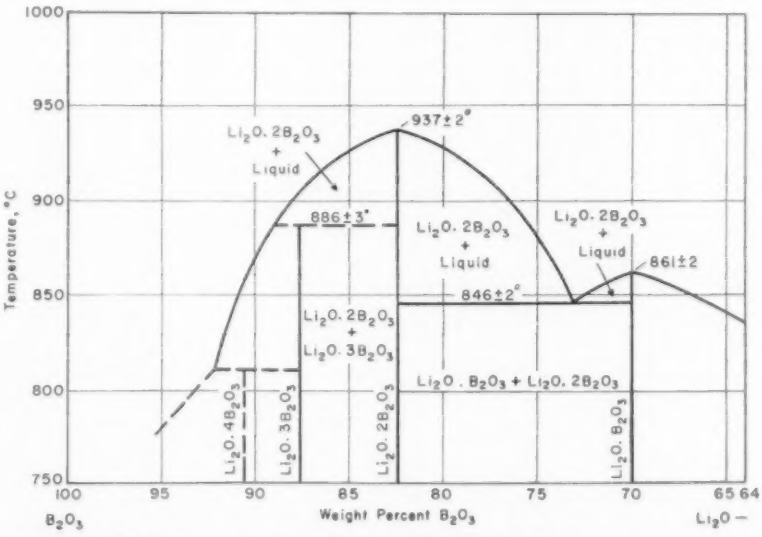

Fig. 1 Tentative phase diagram for the system Li_2O–B_2O_3 (according to B. S. R. Sastry[4])

compounds and mixtures of compounds. The melting points of these mixtures, in a large range of compositions, are considerably lower than the solidus temperatures of most of the silver-base and copper-base brazing alloys.

3. Lithium borates have excellent fluxing properties. The ability of the borates of alkali metals to readily dissolve refractory oxides is well known from analytical chemistry.

The first experimental self-fluxing, airproof brazing alloys containing lithium and boron were found to be airproof and could be used to braze steels in air without additional fluxes. However, it has been recognized that segregation is a problem in the preparation of alloys containing lithium and boron.

The first experimental self-fluxing brazing alloy containing lithium and boron was prepared by gradually dissolving small amounts of boron powder in molten nickel until the eutectic composition, 96% Ni – 4% B, with a melting point of 1140° C (2084° F), was obtained. This eutectic was completely dissolved in molten copper to make an 80% Cu – 19.2% Ni – 0.8% B alloy. Melting of the Cu-Ni-B alloys was carried out in recrystallized alumina crucibles in a 10% H_2 + 90% N_2 atmosphere.

By adding to the 80% Cu – 19.2% Ni – 0.8% B alloy about 5 wt% of lithium, an alloy of the following nominal composition was obtained:* 76.2% Cu – 18.3% Ni – 4.75% Li – 0.75% B. Since the 10% H_2 + 90% N_2 atmosphere was not absolutely dry, the losses of lithium were considerable. The melting range of this alloy was approximately 1900–2000° F. With this alloy, plain carbon steels, alloy steels and stainless steel have been brazed in air, without fluxes or protective atmospheres. Heating was by induction, and the joints were butt brazements of 3-in. long, $^3/_4$-in. diam bars, as illustrated in Fig. 2. The maximum tensile strength of such joints in SAE 1020 steel was 50,000 psi.

It should be pointed out that the particular Cu-Ni-Li-B alloy described above does not have commercial significance for two reasons: (1) the tendency of this alloy to segregate, especially when made in commercial quantities even when prepared using fast cooling such as chill casting, and (2) the high corrosion rate of such an alloy in water. Both of these phenomena arise because of the complete insolubility of lithium in either molten or solid nickel and in solid copper. However, the experiments with this alloy have been considered worth while because of the opportunity afforded for the study and demonstration of the principles involved in the development of self-fluxing, airproof brazing alloys.

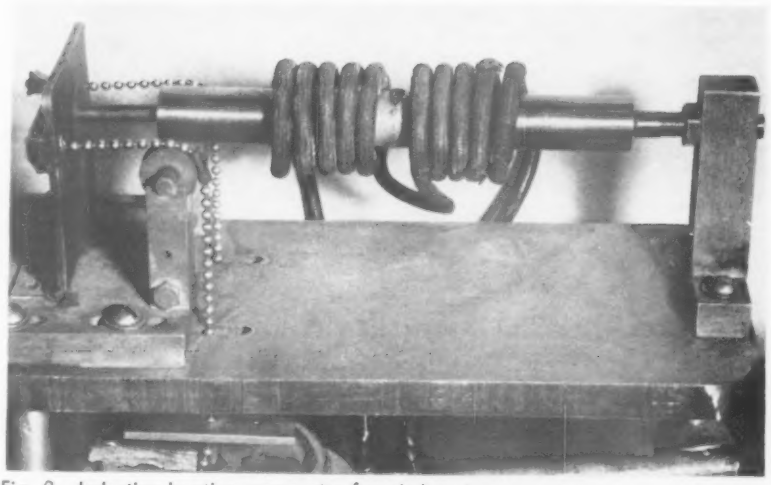

Fig. 2 Induction heating apparatus for air-brazing experiments

It would be desirable at this point to utilize, as a base for a brazing alloy containing both lithium and boron, an element that dissolves larger quantities of both without segregating. Palladium is such an element. However, the expense of palladium-base alloys may rule out their use as brazing filler metal.

Preliminary experiments have shown that it is not feasible to prepare self-fluxing brazing alloys containing silver and boron, without a separation in two phases, presumably due to the fact that silver and boron are completely insoluble in each other.

From Table 3 it can be seen that the melting point of B_2O_3 is 450° C, much lower than the melting point of any of the lithium compounds listed. One might expect, therefore, that a self-fluxing, airproof brazing alloy could be formulated including boron without lithium. This was attempted, but it was found that Cu-Ni-B alloys were not self-fluxing. Two possible explanations exist: (1) the affinity of boron for oxygen is not high enough or (2) the viscosity of B_2O_3 is too great to flow readily. The latter explanation brings up the third requirement of a self-fluxing, airproof brazing alloy, which is that the viscosity of the flux formed be low enough so that it can be displaced in the capillary gap by the filler metal. This viscosity requirement applies, of course, to all brazing or soldering fluxes. It is believed that the viscosity consideration is probably responsible for the failure of the Cu-Ni-B alloys to be self-fluxing. It is known that borates in general are glassy and viscous when molten, but surprisingly the lithium borate flux obtained when brazing with Cu-Ni-B-Li did not detract from its airproof qualities.

Summary

1. A self-fluxing, airproof brazing alloy can be made by adding another highly reducing element to a lithium-bearing brazing alloy. This element must have the same high affinity for oxygen at brazing temperatures as has lithium. The most important prerequisite for obtaining airproof brazing properties is that the binary phase diagram of the two oxides, the lithium oxide and the oxide of the other highly reducing element, must have at least one eutectic point with a melting point considerably below the solidus temperature of the given brazing alloy.

2. It appears that the combination lithium-boron is almost ideal because: (*a*) both lithium and boron have high affinity for oxygen at brazing temperatures; (*b*) according to the binary phase diagram Li_2O-B_2O_3, the two oxides form a series of low-melting compounds and mixtures of compounds; and (*c*) lithium borates have excellent fluxing properties.

3. Brazing experiments have shown the correctness of the foregoing approach. A Cu-Ni-Li-B alloy has been used to braze steels in air, without fluxes or protective atmospheres. Although this particular alloy is not commercially feasible because of poor corrosion resistance and a tendency for segregation in its preparation, it demonstrates the principles outlined. Both difficulties are due to the complete insolubility of lithium in solid nickel or copper, and due effort is being and will be devoted to a search for suitable and practical alloys capable of dissolving both lithium and boron.

Acknowledgments

The authors wish to express their appreciation to the Lithium Corpora-

* An exact chemical analysis of alloys containing Li and B, at least at the present time, is not feasible, since no analytical methods are available for the determination of elementary lithium in this type of alloy. The lithium content determined by existing analytical methods yields that present as Li_2O, LiOH, Li_2CO_3, $LiBO_2$, etc., as well as elementary lithium.

tion of America for sponsoring this investigation and specifically to Walter Fenton.

In addition, the contributions of William Rostoker and Orville T. Barnett are gratefully acknowledged.

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DISCUSSION BY WILLIAM M. LEHRER

It is well to dwell, at this time, on the clarification and distinction between the terms assigned to filler alloys as self-fluxing and/or air-brazing. It is first recognized that an alloy that can be considered "air-brazing" must be self-fluxing. The reverse, however, does not hold. Furthermore, these descriptive terms may be applied in this writer's opinion, only when the atmosphere conditions are clearly expressed and the composition of the base material known. Brazing temperature is another variable that may convert a self-fluxing designated filler alloy to an air-brazing designation. Brazing atmospheres are usually defined in the broad terms of reducing, neutral or inert, or oxidizing. With torch brazing, any of the three may be obtained with proper adjustment of the combustible gas to oxidizing gas ratio. However, regardless of the flame condition, the conditions of torch brazing are primarily oxidizing due to the moisture produced by the flame and the fact that under practical brazing heating conditions, neither the capillary nor the filler alloy is completely enveloped by the reducing-flame atmosphere. Thus, for fluxless brazing with the torch, a truly air-brazing filler alloy is required. Due to the atmosphere conditions stated above, that of primarily oxidizing, the air-brazing designation may only be applied if the filler alloy is capable of reducing or dissolving the surface oxides. Here, composition of the material to be brazed plays a significant role in regards to: 1, the chemical stability of the surface oxides formed during heating (free energy of the oxide formation); 2, the physical nature of the surface oxides (melting point, adherency, solubility in other oxides and in both the filler alloy and base material); and 3, a physiochemical consideration, that the thickness or quantity of surface oxide formed. The chemical stability of the oxides has been presented, as has been the formation of fusible slags, etc. However, the quantity of surface oxide formed has not. This point is brought out due to the fact that present self-fluxing, air-brazing alloys for steels, e.g., Cu-Ni-B-Li,* have been found to be more effective in the brazing of stainless steels that have a limited scale formation on heating than low-carbon steels which scale considerably. The paradox existing is that the presence of Cr_2O_3 in the stainless, although requiring a greater reducing energy, actually is easier to air-braze than low-carbon steel in which the easily reducible Fe_xO_y is present. Thus, a filler alloy that is air-brazing for one steel composition may fail with another and rate as self-fluxing only.

Under an inert atmosphere of argon or helium, very often the filler alloy will flow if it is self-fluxing for some steels but must have air-brazing qualifications for others. By the same token, superalloys containing titanium and/or aluminum brazed under dry H_2 would require a self-fluxing filler alloy but under argon would require the properties of an air-brazing filler alloy. This is due to the reduction of all the surface oxides with the exception of TiO_2 and Al_2O_3 by the H_2 thus leaving only these oxides to be handled by the self-fluxing additions to the filler alloy. Under argon or helium, however, all the oxides are present and, depending on the purity of the inert gas, will increase in amount depending on the length of time in reaching temperature and, so mentioned, the oxidation resistance of the steel.

It has been clearly indicated by the above considerations that the development of a self-fluxing filler alloy, *per se*, has an extremely broad scope and must be considerably narrowed to encompass a specific set of alloys at a definite brazing temperature under a given atmosphere.

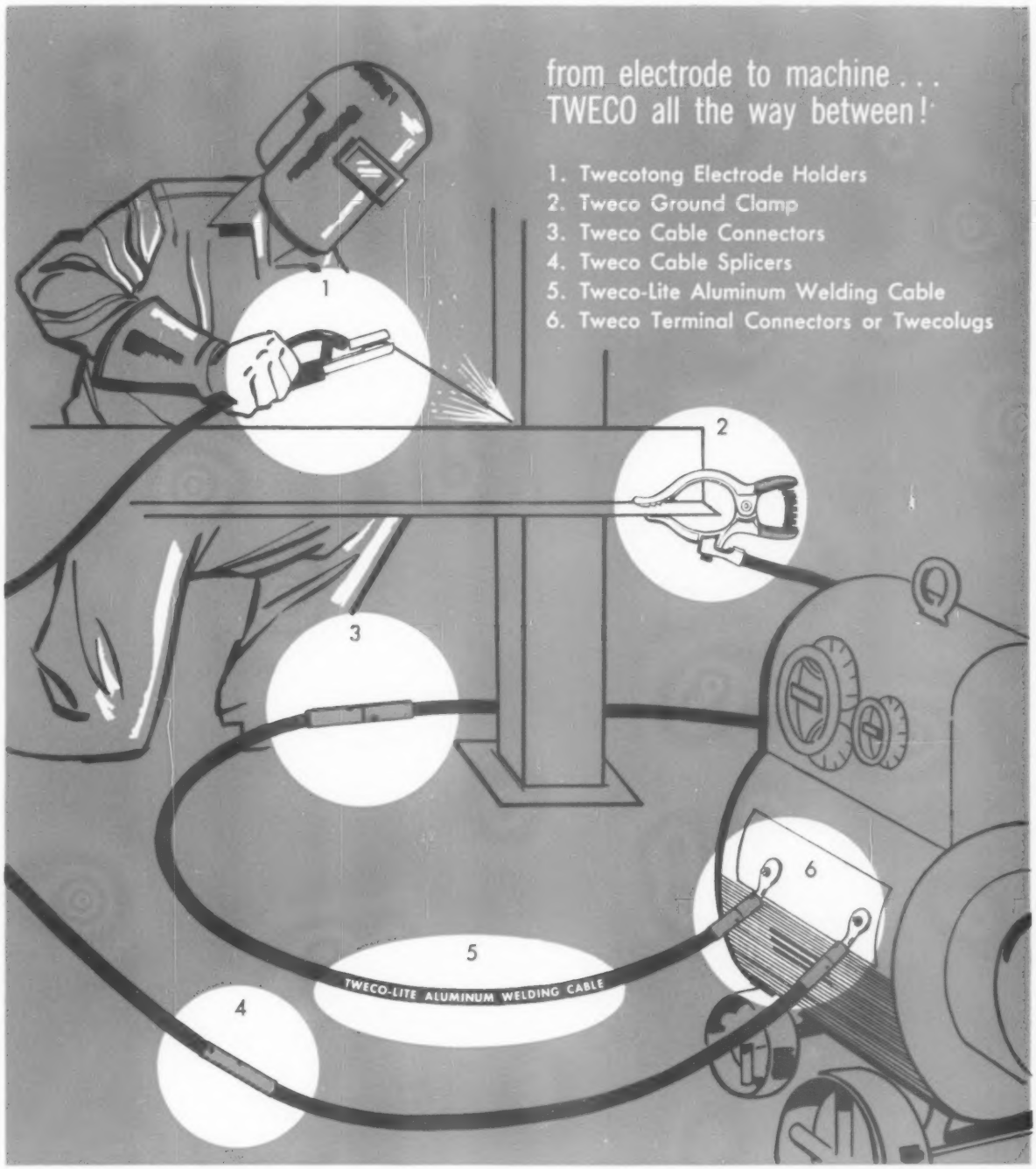
William M. Lehrer is associated with Armour Research Foundation, Chicago, Ill.

* N. Bredzs, U. S. Patent No. 2,768,393, Oct. 30, 1956.

AUTHOR'S CLOSURE

The discussor is sincerely thanked for his contribution which undoubtedly is very helpful for setting more accurate definitions of the "self-fluxing" and "air-brazing" alloys. It shows also that the dividing line between these two groups of alloys has to be set considering all the factors determining whether the given atmosphere is oxidizing or reducing.

The contribution does not affect the conclusions of the paper, nor the theoretical requirements set down for development of "air-brazing alloys."



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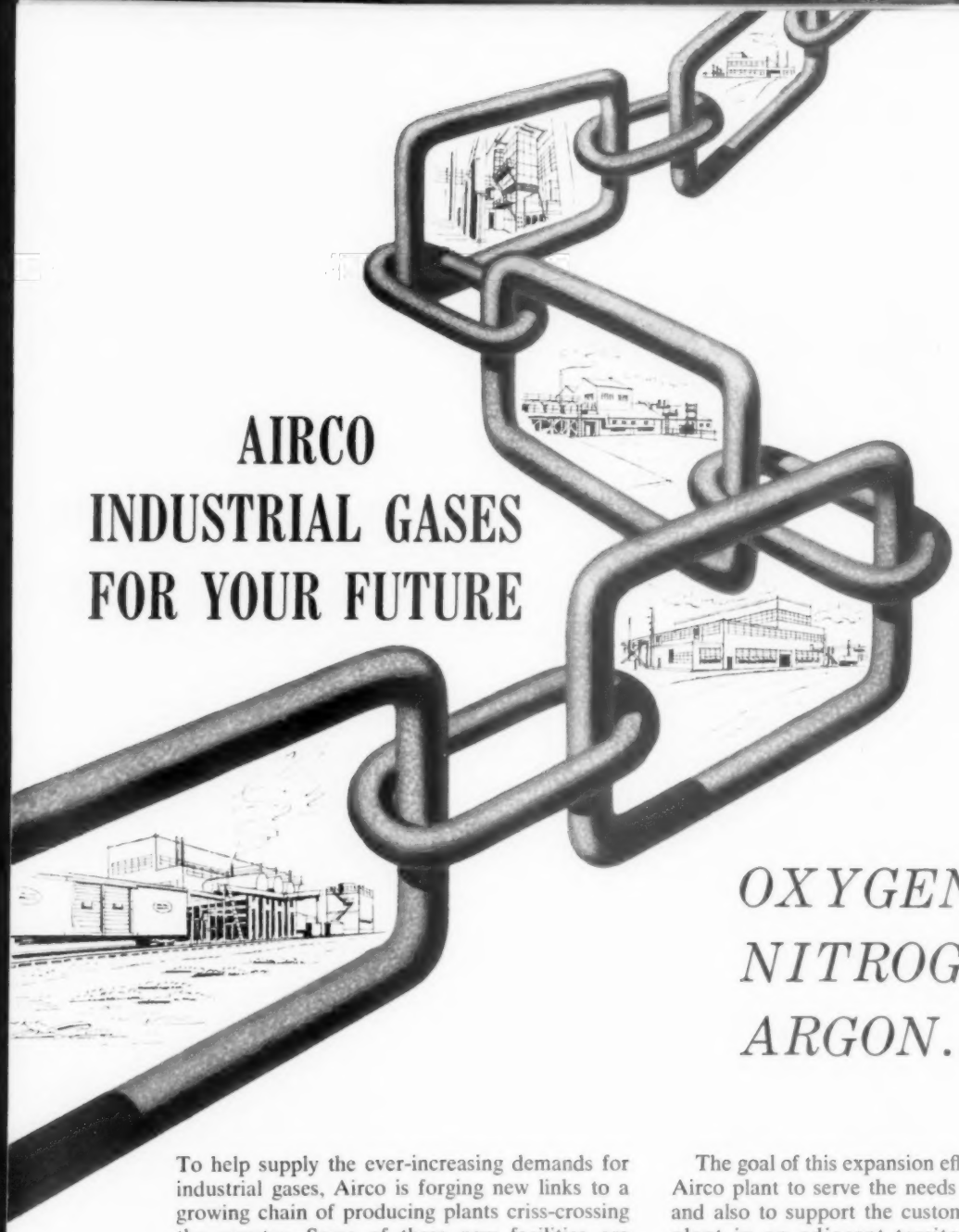

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